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Canada Centre for Mineral and Energy Technology

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Canada

SEABED SUBSIDENCE PROFILES OVER THE PHALEN COLLIERY DERIVED FROM ANALYSIS OF SEAFLOOR TOPOGRAPHY DATA

McGregor GeoScience Limited

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EXECUTIVE SUMMARY

Bathymetric data, collected by McGregor (1988,1989,1990), was used to generate subsidence profiles over the Phalen Colliery. This work was undertaken on behalf of the Canada Centre for Mineral and Energy Technology (CANMET), Cape Breton Coal Research Laboratory.

The analysis of the bathymetric data was executed in two stages. The first stage involved the generation of a preliminary subsidence profile from Line 15 and the analysis of its characteristics. Point digitized digital bathymetric profiles of McGregor (1989, 1990) were used in this investigation. In the second stage, original analogue bathymetric records were stream digitized and used to generate subsidence profiles for Lines 4, 5, 6, 14, 15, and 16.

The raw subsidence profile for Line 15, produced by subtracting the post-mining bathymetric profile from the pre-mining bathymetric profile, clearly showed subsidence in the area of the Phalen 1E Longwall. The raw profile is, however, also affected by high frequency variations caused by the effects of boat motion on the original bathymetric profiles. A 20 m moving average operator was applied to the digital bathymetric profiles to remove these high frequency variations from the subsidence profile.

No relationship exists between the horizontal offset between pre-mining and post-mining survey lines and the accuracy of the measured subsidence profile. This is due mainly to the laterally continuous nature of the seafloor features.

The standard deviation of portion of the subsidence profile not affected by subsidence was used here as the measure of subsidence profile accuracy. Though a correlation exists between many of the larger variations in the subsidence profile not related to subsidence and seafloor slope, it is not possible to use seafloor slope to compliment standard deviation as an indicator of measurement accuracy.

Stream digitization was used to remove any effects of sample interval from the subsidence profiles. All subsidence profiles generated from the stream digitized data showed subsidence over either the Phalen 1E or 1W Longwall. Preliminary subsidence profiles from Lines 4, 5, 6, and 14 displayed apparent emergence south of the subsided zone. Changes in the velocity of sound in water over the 1987 survey are thought to the cause of this apparent emergence. Apparent emergence was removed by subtracting the linear trend from the subsidence profile.

The subsidence profiles, corrected for apparent emergence, showed an average subsidence of 0.83 m and an average total subsidence length of 335 m. Subsidence profiles were generally asymmetric in shape. The accuracy of the subsidence profiles, quantified in the standard deviation, averaged at 0.15 m. Profiles from Lines 15 and 16 appear more accurate (Average standard deviation 0.11 m) than those from Lines

4, 5, 6, and 14 (Average standard deviation 0.16 m). The higher standard deviation is due to the slightly lower resolution of the 1987 data used in the latter four lines as the pre-mining profile.

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Résumé exécutif

Des données de bathymétrie prélevées par McGregor (1988, 1989, 1990) ont été utilisées pour générer des profils d'affaissement au-dessus de la mine de charbon Phalen. Ce travail a été entrepris pour le compte du Centre canadien de la technologie des minéraux et lénergie (CANMET), Laboratoires de recherche sur le chabon du Cap Breton.

L'analyse des données bathymétriques a été exécutée en deux étapes. La première étape comprenait la génération d'un profil d'affaissement préliminaire à partir de la ligne 15 et l'analyse des caractéristiques de ce profil. Des profils de bathymétrie digitale, digitalisés en mode ponctuel, de McGregor (1989, 1990) ont été utilisés dans cette enquête. Au cours de la seconde étape, les relevés originaux de bathymétrie analogiques ont été digitalisés en mode continue et utilisés pour générer des profils d'affaissement pour les lignes 4, 5, 6, 14, 15, et 16.

Le profil d'affaissement brut pour la ligne 15 a été produit en soustrayant le profil bathymétrique post-exploitation minière du profil bathymétrique pré-exploitation minière. Ce profil d'affaissement montre clairement la subsidence active dans la région de la longue taille Phalen 1 Est. Toutefois, le profil brut est aussi affecté par les variations de haute fréquence dans les profils bathymétriques originaux et causées par les mouvements du bateau. Un opérateur de moyenne glissante d'un longueur de 20 m a été appliqué aux profils de bathymétrie numériques pour éliminer ces effets du profil d'affaissement.

Aucune relation n'existe entre les décalages horizontaux entre les lignes de levés pré-exploitation et post-exploitation minière, et la précision du profil d'affaissement mesuré. Ceci est principalement dû à la nature latéralement continue des caractéristiques du fond marin. L'écart-type de la portion du profil d'affaissement non-affecté par la subsidence a été utilisé ici comme mesure de la précision du profil d'affaissement. Quoiqu'une corrélation existe entre plusieurs des plus grandes variations dans la profil d'affaissement et que ces variations ne soient reliées ni à l'affaissement, ni à la pente du fond marin, il n'est pas possible d'utiliser la pente du fond marin pour complémenter l'écart-type comme indicateur de précision des mesures.

La digitalisation en mode continu a été utilisée pour extraire tout effet d'interval d'échantillonnage des profils d'affaissement. Tous les profils d'affaissement générés à partir des données digitalisées en mode continu, ont montré de l'affaissement au-dessus de l'une ou l'autre des longues tailles Phalen 1 Est et 1 Ouest. Les profils d'affaissement préliminaires des lignes 4, 5, 6 et 14 ont tous présenté de l'émergence au sud de la zone affaissée. Des changements dans la vélocité du son dans l'eau sont soupçonnés d'être la cause de cette émergence apparente. L'émergence apparente a été corrigée en soustrayant la composante linéaire des profils d'affaissement.

Les profils d'affaissement ont montré un affaissement moyen de 0.83 m et une moyenne de 335 m pour la longueur affaissée totale. Les profils d'affaissement étaient généralement de forme asymétrique. En moyenne, la précision des profils d'affaissement, telle que quantifiée par l'écart-type, était de 0.15 m. Les profils des lignes 15 et 16 paraissent plus précis (écart-type, moyen de 0.11 m) que ceux des lignes 4, 5, 6 et 14 (écart-type moyen de 0.16 m). Dans le cas de ces 4 dernières lignes, l'accroissement de l'écart-type est dû à la résolution légèrement plus basse des données de 1987 qui sont utilisées comme profil pré-exploitation minière.

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SECTION 1

INTRODUCTION

The Phalen Colliery is located in northern Cape Breton, west of Glace Bay, Nova Scotia as shown in Figure 1. The Phalen mine workings extend northward from the Cape Breton coastline (Figure 2) and are located in an area covered by the waters of the Gulf of St. Lawrence. In an effort to detect seafloor subsidence, high resolution bathymetric data was collected over the Phalen Colliery in 1987, 1988, and 1989 on the lines shown in Figures 3 and 4. To identify zones of seafloor subsidence and estimate the amount of subsidence, McGregor (1989, 1990) compared pre-mining bathymetric profiles to post-mining profiles. The objective of this work are threefold: 1) To derive subsidence profiles from the bathymetric profiles, 2) To measure the amount of subsidence, and 3) To derive an indicator of the accuracy of the subsidence measurements.

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SECTION 2

REPORT ORGANIZATION

The remainder of this report is broken into four sections. In Section 3, the methodology used to examine the bathymetric data, produce subsidence profiles, and estimate subsidence profile accuracy is presented. Section 4 is a discussion of the characteristics of the derived subsidence profiles. Conclusions and recommendations are given in Sections 5 and 6, respectively.

All figures discussed in this work are presented in Appendix 1. Tables are presented in Appendix 2.

SECTION 3

METHODOLOGY

The analysis of the bathymetric data to produce subsidence profiles over the Phalen colliery was executed in two phases. In the first phase, point digitized data from Line 15 taken from AutoCAD drawing files and digital bathymetric profiles of McGregor (1989, 1990) was used to provide a preliminary evaluation of the nature of subsidence profiles over the Phalen Colliery.

In the second phase, original analogue bathymetric profiles from six lines identified by McGregor (1990) as having the greatest amount of subsidence (Lines: 4, 5, 6, 14, 15, and 16) were stream digitized. This stream digitized data was used to produce subsidence profiles from the pre-mining and post-mining line pairs shown in Table 1.

PHASE 1: Point Digitized Data From Line 15

a) Track Offset versus Depth Offset

Pre-mining and post-mining bathymetric profiles, presented in McGregor (1989, 1990), indicate that the seafloor over the Phalen Colliery is extremely irregular. As a result of this irregularity, small horizontal offsets between the pre-mining and post-mining profiles may result in large differences in the measured bathymetric profiles. Track plots of horizontal locations of the pre-mining and post-mining profiles (Figures 3 and 4) indicate that horizontal offsets (Track Offsets) of up to 25 m exist between these line pairs. It is therefore possible that any lack of correlation between pre-mining and post-mining

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bathymetric profiles (not attributable to subsidence) may be caused by differences in the measured depth resulting from track offsets.

Measurements of offset between pre-mining and post-mining profiles (Depth Offset) and track offset from Line 15 were point digitized from the AutoCAD drawing files of pre-mining and post-mining bathymetric profiles developed by McGregor (1989, 1990). Depth offset and track offset pairs were computed for each of the possible line pair combinations for Line 15 shown in Table 2. To avoid biasing the analysis by the data collected in the subsided zones, only line pairs collected in the same year were used as the basis of this analysis of the depth offset versus track offset relationship. Plots of this data, shown in Figures 5 and 6, display a large scatter about the zero depth offset axis with no linear trends. Thus, it was concluded that no relationship exists between depth offset and track offset and that the measured bathymetric profiles are not strongly affected by the difference between the horizontal position of the pre-mining and post-mining track lines.

Support for this argument was derived from the comparison of bathymetric profiles from adjacent survey lines. Because the survey lines were run in a general north-south direction, roughly perpendicular to the strike of the seafloor topography, the main topographic features are consistent from line to line (Figures 7 and 8). Therefore, relatively small differences between the horizontal position of the pre-mining and post-mining profiles should not result in large differences in the depth offset.

b) Subsidence Profile Accuracy

A subsidence profile, generated by subtracting the point digitized post-mining bathymetric profile from the pre-mining bathymetric profile of Line 15 is shown in Figure 9. Data gaps in this figure indicate areas on Line 15 where no digital data was available from the digital data files. Although subsidence is clearly evident between shot points 2030 and 2050, the profile is also affected by high frequency variations over its entire length.

The accuracy of this preliminary subsidence profile is limited by the amplitude of these high frequency variations. This amplitude was determined from the scatter of subsidence data unaffected by subsidence about the zero subsidence axis. The parameter used to quantify the scatter in this report is the standard deviation.

To get an estimate of the accuracy of the raw subsidence profiles, the standard deviation of subsidence profiles generated from data collected in the same year was calculated. As shown in the histograms of Figures 10 and 11, the average standard deviation of the 1988 and 1989 data is 0.31 m. Given that profiles collected in the same year should show the strongest correlation these results suggest that limit of accuracy of the preliminary subsidence profiles generated for Line 15 should also be 0.31 m.

Subsidence profile accuracy was also calculated from the standard deviation of the northern section of the subsidence profile not affected by subsidence. This value (0.328) correlates well with the data from Figures 10 and 11, suggesting that it is also an appropriate method of quantifying subsidence profile accuracy. This latter method was used to

measure standard deviation for the remaining subsidence profiles described in this report.

c) Effects of Boat Motion on the Subsidence Profile

To investigate possible causes of the relatively high standard deviation of the raw subsidence data from Line 15, the original analogue field records were re-examined. The original data is uncorrected for the effects of boat motion. As a result, the seafloor trace also includes the effect of wave action on the vertical position and roll of the boat. This motion is manifested on the bottom trace as the small scale, high frequency variations of the seafloor, shown in Figure 12. It is these effects of boat motion which are thought to be the cause of the high frequency variation in the subsidence profile.

The effects of boat motion on the data were reduced by applying a moving average to the point digitized bathymetric data and then regenerating the subsidence profile. This averaging results in a "smoothing" of the higher frequency variations in the bathymetric profiles as shown in Figures 13 through 16. A number of averaging intervals were applied to the data from Line 15. The selection of the most appropriate averaging interval based on two factors: 1) The effect of the averaging on the large scale bathymetric features, and 2) The effect of the averaging on the standard deviation of the area of the subsidence profiles not effected by subsidence. For higher averaging intervals, the averaging process induced a change in the character of some of the large scale bathymetric features thought to be indicative of the true seafloor. As shown in Figure 14, the peak between shot point 2047 and 2048 is transformed from a single peak into smaller double

peaks if the averaging interval applied to the 1989 data is increased over 20 m. The effect of the averaging on the standard deviation of the subsidence profile is presented in Figures 15 and 16. With a 20 m averaging interval applied the standard deviation (0.123 m) has been reduced by almost a third of that of the raw data (0.328). Increases in the averaging interval above 20 m result only small decreases in the standard deviation below that of the 20 m interval. Thus, from the effects of the averaging interval on the seafloor topography and the standard deviation of the subsidence profile, it was concluded that the 20 m averaging interval is the most appropriate for the bathymetric profiles over the Phalen Colliery.

d) <u>The Subsidence Profile and the Seafloor Slope</u>

Acoustic profiling methods do not accurately resolve extremely steep seafloor slopes. This is generally due to the fact that acoustic returns generally represent the closest distance from the seafloor to the acoustic transducer and not necessarily the true water depth (see Trabant, 1984). The seafloor over the Phalen Colliery is quite irregular and is characterized by many steep seafloor slopes. Thus, it was thought that the seafloor slope may limit the accuracy of the subsidence profiles generated in extremely irregular seafloor topography over the Phalen mineworkings.

The seafloor slope, calculated from the Line 15 (1989N), 20 m averaged 1989 depth profile, is presented with the 20 m averaged subsidence profile from Line 15 in Figure 17. As many of the larger peaks in the subsidence profiles appear to correlate to where the seafloor slope is very steep, seafloor slope must have some effect on

the accuracy of the generated subsidence profiles. To remove this effect, subsidence profile variations which could be correlated to steep seafloor slopes were manually removed. Unfortunately, there is no one-to-one correlation between the seafloor slope and the subsidence profile variations. Thus, it was concluded that measured seafloor slope cannot be used to compliment standard deviation as an indicator of measurement accuracy.

e) <u>The Subsidence Profile and the Sample Interval</u>

The average horizontal sample intervals of the point digitized in 1988 and 1989 bathymetric files from Line 15 of McGregor (1989, 1990) is 1.8 m and 0.7 m, respectively. Sample intervals were, however, quite variable over the course of Line 15 (0.4-17.6 m) and were not consistent between the pre-mining and post-mining profiles. For this reason, a linear interpolator was used between profiles to relate the depth measurements to common shot point values. The differences in sample interval combined with the applied linear interpolation may, however, have caused errors in the subsidence profile generated from the point digitized data.

Sample interval variations were largest in the Line 15 data from 1988. Sample interval data from this line is plotted in Figure 18 with the 20 m interval subsidence profile. To enhance the sample interval plot, sample intervals were averaged over 2 samples. As correlation exists between some of the peaks in the subsidence profiles and the areas where the horizontal sample interval was high, it was concluded that the accuracy of the subsidence profile is at least in part influenced by the sample interval used to digitized the original

analogue records. Similar to the relationship between slope and subsidence, however, the relationship here is not direct and therefore the sample interval also could not be used to compliment standard deviation as an indicator of measurement accuracy.

To avoid biasing the data by sample interval variations, the original analog records were then stream digitized at a rate much higher than the maximum frequency of observed seafloor variation. It is these stream digitized profiles that are focus of Phase 2.

PHASE 2: Stream Digitized Profiles

a) Digitization of Bathymetric Profiles and Generation of Subsidence Profiles

Both pre-mining and post-mining bathymetric profiles from Lines 4, 5, 6, 14, 15, and 16 were stream digitized. To help maintain the accuracy of the original analogue records, stream digitization was done at a rate much higher than the highest frequency variations of the seafloor. Analogue bathymetric profiles from the lines identified in Table 1 were stream digitized at a rate of 0.025 inch. In this mode, depth values were digitized every 0.025 inch (absolute distance on the analogue paper record) which resulted in an average of 9000 samples per line and a horizontal sample interval of approximately 15 cm along the seafloor.

After digitization and the bathymetric profiles were edited for digitization errors and corrected for horizontal and vertical offsets between the pre-mining and post-mining profiles. Horizontal offsets caused by changes in the location of survey line shot points between surveys were removed by applying static shifts to obtain the best

overall correlation between the pre and post-mining profiles. Smaller scale differences caused by local variations in the vessel speed during the survey were removed by either shifting, compressing or expanding small sections of the bathymetric profiles. Static vertical shifts were also applied to the profiles to accommodate differences in tidal variations between surveys. An example of the edited bathymetric profiles is presented in Figure 19.

The 20 m averaging function was applied to the offset corrected data. Subsidence profiles were then generated from the averaged data by subtracting the post-mining profiles from the pre-mining profiles. To determine the accuracy of the measured subsidence, the standard deviation was calculated from the northern section of the subsidence profiles not affected by subsidence.

b) Curve Fitting

To aid in the measurement of the characteristics of the subsidence profiles, each profile was run through a curve fitting routine. This routine used a nonlinear regression to fit one of the exponential functions shown in Equations 1 and 2 to the measured data. These functions, shown in the examples of Figures 20 and 21, are similar in shape to a negative Gaussian probability density function. To allow for asymmetry, the functions were divided at the profile axis and the individual halves of each function were allowed to vary independently while being held equal at the profile axis.

(1) a) North of profile axis:

$$y(x) = \frac{-be^{\left(-\frac{\left(\frac{(x-m)}{t}\right)^2}{2}\right)}}{\sqrt{2\pi}}$$

b) South of profile axis:

$$y(x) = \frac{-be^{\left(-\frac{\left(\frac{(x-m)}{s}\right)^2}{2}\right)}}{\sqrt{2\pi}}$$

(2) a) North of profile axis:

$$y(x) = \frac{-be^{\left(-\frac{\left(\frac{(x-m)}{t}\right)^2}{2}\right)}}{\sqrt{2\pi}}$$

b) South of profile axis:

$$y(x) = \frac{c-be^{\left(-\frac{\left(\frac{(x-m)}{s}\right)^2}{2}\right)}}{\sqrt{2\pi}}$$

Where:

x = Distance north of the longwall axis (m).
y = Subsidence (m).
m = Location of the profile axis (mN of longwall axis).
b = Maximum subsidence (m).
s = The standard deviation of the north half of subsidence curve about the profile axis (m).
t = The standard deviation of the north half of subsidence curve about the profile axis (m).
c = A constant included to accommodate apparent emergence on Lines 4, 5, 6, and 14 (see section c), Apparent Emergence).

Coefficients for all curves fit to subsidence profiles over the Phalen colliery are presented as Table 3.

c) Apparent Emergence

The initial subsidence profiles generated for Lines 4, 5, 6, 14, 15 and 16 from the stream digitized data are presented in Figures 22 through 31. Characteristics of these preliminary profiles are presented in Table 4. An obvious difference exists between the profiles from Lines 15 and 16 and profiles from the remaining four lines. Lines 4, 5, 6, and 14 show apparent emergence south of the zone of subsidence whereas no emergence is evident on Lines 15 and 16.

Causes of Apparent Emergence

The apparent emergence on the subsidence profiles from Lines 4, 5, 6, and 14 is not thought to be representative of true seafloor emergence between the pre-mining and post-mining surveys. As apparent emergence is only evident on the lines where 1987 data was used for the pre-mining profile, some difference in the between the 1987 and 1988 field surveys is suggested. Four possible causes for this apparent emergence are discussed here: 1) Operational differences between 1987 and 1988, 2) Tidal variations, 3) Sediment deposition, and 4) Changes in acoustic velocity.

Operational differences

To maintain consistency between pre-mining and post-mining surveys, McGregor employed the same survey equipment and vessel for each survey. The first bathymetric survey done by McGregor

GeoScience was executed in 1987. Though it is more likely that the 1987 data is affected by problems due to inexperience, it appears improbable that any problems caused by inexperience of the geophysical operators and vessel crew could result in a systematic change in the measured depth over a number lines.

Data from 1987 was, however, recorded at a slightly faster vessel speed than the data from 1988. It was also collected in a dual frequency mode whereas the 1988 data was collected using the high frequency transducer only. The combination of these two factors resulted in a slight decrease in the resolution of the 1987 data, relative to 1988 and 1989 data. While this can explain differences in the standard deviation of the subsidence profiles between those employing 1987 and 1988 data, this decrease in resolution would not result in a large change in the measured depth over the course of the 1987 survey lines. Thus, it was concluded that operational differences between the 1987 and 1988 survey are not the cause of the apparent emergence on Lines 4, 5, 6, and 14.

Tidal variations

On survey lines which take many hours to collect, the effect of tidal cycles on the measured water depth is quite strong. Lines collected over the Phalen Colliery took, on average, 15 minutes to collect. Given the 12 hour tidal cycle in the northern Cape Breton area the effect of tidal variations on these short line is therefore quite small. Tidal variations would also result in changes in the measured depth which were dependent on the direction which the survey line was run. Apparent emergence on the

subsidence profiles always occurs on the southern end of the survey lines, regardless of which direction the survey lines were run. Thus, it concluded that tidal changes variations cannot be the cause of the emergence evident on the four lines where 1987 data was employed as the pre-mining data.

Sediment deposition

Deposition of sediment south of the subsided areas could also cause apparent emergence between the 1987 and 1988 surveys. This would require the deposition of 0.20 to 0.74 m of sediment in between 1987 and 1988 (see Table 4). It would also require that no sediment be deposited between 1988 and 1989. The lack of a large sediment source, such as a major river near the Phalen Mine combined with the exposed nature of this area of north Cape Breton suggests, however, that the survey area is probably more affected more by erosion than deposition.

Sediment deposition should result in a smoothing of the bathymetric profiles due to the selective infilling of seafloor depressions. As no evidence of such smoothing exists on the bathymetric profiles (see Figure 19), it was concluded that apparent emergence on the subsidence profiles from Lines 4, 5, 6, and 14 is not due to sediment deposition between 1987 and 1988.

Changes in acoustic velocity

Acoustic bathymetric profiling is dependent on the velocity used to convert the travel time of the acoustic wave in the water into a depth below sealevel. This velocity, which is controlled by

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the salinity, temperature, and pressure conditions of the seawater, was calibrated near the centre of the survey area using the standard bar check method. This bar checked velocity was then used for the whole survey area.

The bar check for the 1987 survey was completed to a maximum depth of 8.67 m. If the water column depth during this survey is well mixed and the acoustic properties consistent with depth, as in the one layer case of Figure 32a, the velocities determined from the bar check will be accurate throughout the survey area. If, however, the water column was layered during the pre-mining survey, with a higher velocity layer below the maximum depth of the bar check (Figure 32b), the velocity derived from the bar check is not accurate over the full length of a survey line. In depths greater than the maximum bar check depth, the bathymetric profile will appear shallower than the true seafloor profile.

These errors in the depth measurement are then carried into the derived subsidence profiles. To remove the effects of tidal variations, the pre-mining and post-mining profiles were shifted vertically to give the best correlation of the two profiles in the area north of the zone of subsidence. With the two profiles aligned in this manner (Figure 32c), the post-mining profile then appears shallower than the pre-mining profile south of the zone of subsidence, resulting in apparent emergence.

As a preliminary test of this hypothesis, the average measured emergence was compared to the amount of emergence predicted by increasing the water velocity by 30 m/s. In the 1987 survey, a

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velocity of 1457 m/s was measured from the bar check. When the velocity is increased to 1487 m/s (still well within the normal range of average velocities of sea water), an average error of approximately 0.37 m is introduced into the depths measured north of the zone of subsidence. As average apparent emergence is 0.31 m (Table 4), it is reasonable to use the higher velocity layer to explain the apparent emergence.

The character of the subsidence profiles from Lines 4, 5, 6, and 14 provides further support for a high velocity layer as the cause of apparent emergence. The presence of a the high velocity layer causes a slight difference in the overall trend of the pre-mining and post-mining profiles (see Figure 32c). This difference is then be translated into a trend in the subsidence profile which increases to the south. Southward increasing trends similar to that shown in the example of Figure 34 are evident on all subsidence profiles from Lines 4, 5, 6, and 14. This information combined with the fact that a relatively small increase in the water velocity can result in apparent emergence on the same scale as observed on the subsidence profiles, led to the conclusion that the apparent emergence evident on the subsidence profiles from Lines 4, 5, 6, and 14 is due to higher velocity layer below the maximum depth of the bar check during the 1987 survey.

Removal of Apparent Emergence

As shown in Figure 34, the trend in the subsidence profiles could be modelled with a linear regression of the sections of the subsidence profile unaffected by subsidence. This linear trend was

then subtracted from the subsidence profiles and the 1987 bathymetric profiles from Lines 4, 5, 6, and 14 to remove the effects of the high velocity layer. The profiles from Lines 4, 5, 6, and 14 with apparent emergence removed are presented in Figures 34 through 41. Characteristics of all subsidence profiles after the removal of apparent emergence are summarized in Table 5.

SECTION 4

SUBSIDENCE PROFILE CHARACTERISTICS

The subsidence curves fit to the measured subsidence profiles are presented in Figures 42 and 43. Figure 42 displays curves which were collected over the Phalen 1W longwall (Lines 4, 5, and 6). Depicted in Figure 43 are curves from Lines 14, 15, and 16 which are over the Phalen 1E longwall.

The average values of the subsidence profile characteristics measured from the fitted curves are presented at the bottom of Table 5. The average depth of subsidence is 0.83 m and the average standard deviation of the subsidence profiles is 0.15 m. The axes of the subsidence profiles are located, on average 46 m north of the longwall axes and the average total length of the subsided area is 335 m. The subsided area south of the profile axis averages 143 m in length and the area north of the profile axis averages at 193 m.

Subsidence profiles are also generally characterized by single troughs which are generally asymmetric with the profile axes offset to the north of their respective longwall axes. The exception to this is the profile from Line 5 which is characterized by two troughs with the southern most trough located just south of its longwall axis. Some smaller secondary zones of subsidence also exist at the northern end of some subsidence profiles from Lines 6 and 14. As these secondary zones only occur in profiles from 1987 and 1988 data, it is likely they are due to local variations in the water velocity during the 1988 survey.

All subsidence profiles, except Line 15, are asymmetric in shape. Profiles over the 1E longwall (14, 15, and 16) generally display

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profiles with the steeper slope to the North. Profiles from Lines 4, 5, and 6 do not show any consistency in the pattern of asymmetry.

Standard deviation of the subsidence profiles appears to be related to the year in which the data was collected. For Lines 4, 5, 6, and 14, the standard deviation of the measured subsidence profiles averages at 0.16 m. For Lines 15 and 16, the average is 0.11 m. As discussed in Section 3, this lower standard deviation is due to a decrease in resolution in the 1987 data caused by the combined effects of the use of a dual frequency mode and a slightly higher vessel speed during data collection.

SECTION 5

CONCLUSIONS

The generation of subsidence profiles from high resolution bathymetric profiles was divided into two phases. In the first phase, point digitized bathymetric profiles from Line 15 were used to provide a preliminary examination of subsidence profile characteristics. In the second phase stream digitized bathymetric profiles were used to derive subsidence profiles and measurement accuracies for selected line pairs from Lines 4, 5, 6, 14, 15, and 16. The conclusions from each are described below.

PHASE 1:

A) No relationship exists between the horizontal offset in the track lines and the offset in depth between pre-mining and post-mining profiles. This lack of a relationship is due to the laterally continuous nature of the seafloor topography.

B) The raw subsidence profile generated from the point digitized data from Line 15 clearly displayed a zone of subsidence but was characterised by high frequency variations caused by boat motion during the field survey. These variations limit the accuracy of the raw subsidence to approximately 0.31 m.

C) A moving average operator applied to the raw bathymetric data reduced the amplitude of these smaller scale variations. The operator with an averaging interval of 20 m produced the best result for subsidence profiles over the Phalen Colliery, reducing the standard

deviation of the subsidence profile to almost a third of the raw subsidence profile.

D) Steep seafloor slopes and high sample intervals have some effect on the subsidence profile. The effects of steep seafloor slopes were manually removed from the subsidence profile. The relationship between the subsidence profile and seafloor slope as well as between the subsidence profile and sample interval is not one-to-one.

Phase 2:

A) Initial subsidence profiles from Lines 4, 5, 6, and 14 show apparent emergence south of the subsided area. This apparent emergence is due to the presence of a high velocity water layer below the maximum bar check depth during the 1987 survey. Subsidence profiles affected by apparent emergence display a linear trend caused by the high velocity layer. Apparent emergence was removed from these profiles by removing the linear trend.

B) Subsidence profiles from Lines 4, 5, 6, and 14 show a higher average standard deviation than Lines 15 and 16. This is caused by a decreased resolution in the 1987 pre-mining bathymetric data.

C) Subsidence was observed on all lines examined in this report. The average observed subsidence was 0.83 m, with the maximum of 1.36 m occurring on Line 14. Average standard deviation of the subsidence profiles away form the zones of subsidence suggest that the accuracy of the bathymetric method is 0.15 m.

SECTION 6

RECOMMENDATIONS

Although the results of the subsidence profiles presented in this work are quite promising, it may be possible to improve the accuracy of subsidence profiles of data collected in future surveys. Recommendations for future work are given below:

1) Velocity Calibration: As discussed in Section 3, the apparent emergence evident on the subsidence profiles from Lines 4, 5, 6, 14 is caused by a change in water velocity over the 1987 survey lines. To avoid the errors caused by a high velocity layer in the deeper areas to the north which resulted in apparent emergence, bar check calibrations of the water velocity should be performed in many locations and many different depth in the survey area. Changes in water velocity with location/depth could then be mapped to permit for post survey corrections to the recorded depth.

2) Surveying Techniques: A strong degree of consistency in field methods has been maintained through the three field surveys conducted by McGregor over the Phalen Colliery. This has allowed the direct comparison of data from all three years. Newer survey techniques which would enhance the results presented here should, however, be considered any future surveys. Of particular interest to this type of application is a multibeam bathymetry system. Multibeam systems can obtain on average 12 bathymetric profiles with one pass on a survey line and can be used to give complete bathymetric coverage over a given survey area. This volume of information would considerably improve the statistical accuracy of any subsidence measurements and would allow the generation

of three dimensional images of the seafloor and subsidence troughs over the mined longwalls.

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McGregor GeoScience Limited, 1988. Determination of Seafloor Topography over the New Phalen Colliery, Sydney Coalfield, Cape Breton, Nova Scotia. Unpublished report submitted to Cape Breton Coal Research Laboratory, March 1988.

McGregor GeoScience Limited, 1989. Seafloor Topography over the Phalen Colliery, Phase 2, Sydney Coalfield, Cape Breton, Nova Scotia. Unpublished report submitted to Cape Breton Coal Research Laboratory, June 1989.

McGregor GeoScience Limited, 1990. Seafloor Topography over the Phalen Colliery, Phase 3, Sydney Coalfield, Cape Breton, Nova Scotia. Unpublished report submitted to Cape Breton Coal Research Laboratory, April 1990.

Trabant, P. K., 1984. Applied High Resolution Geophysical Methods. International Human Resource Development Corporation, Boston.

APPENDIX 1

FIGURES

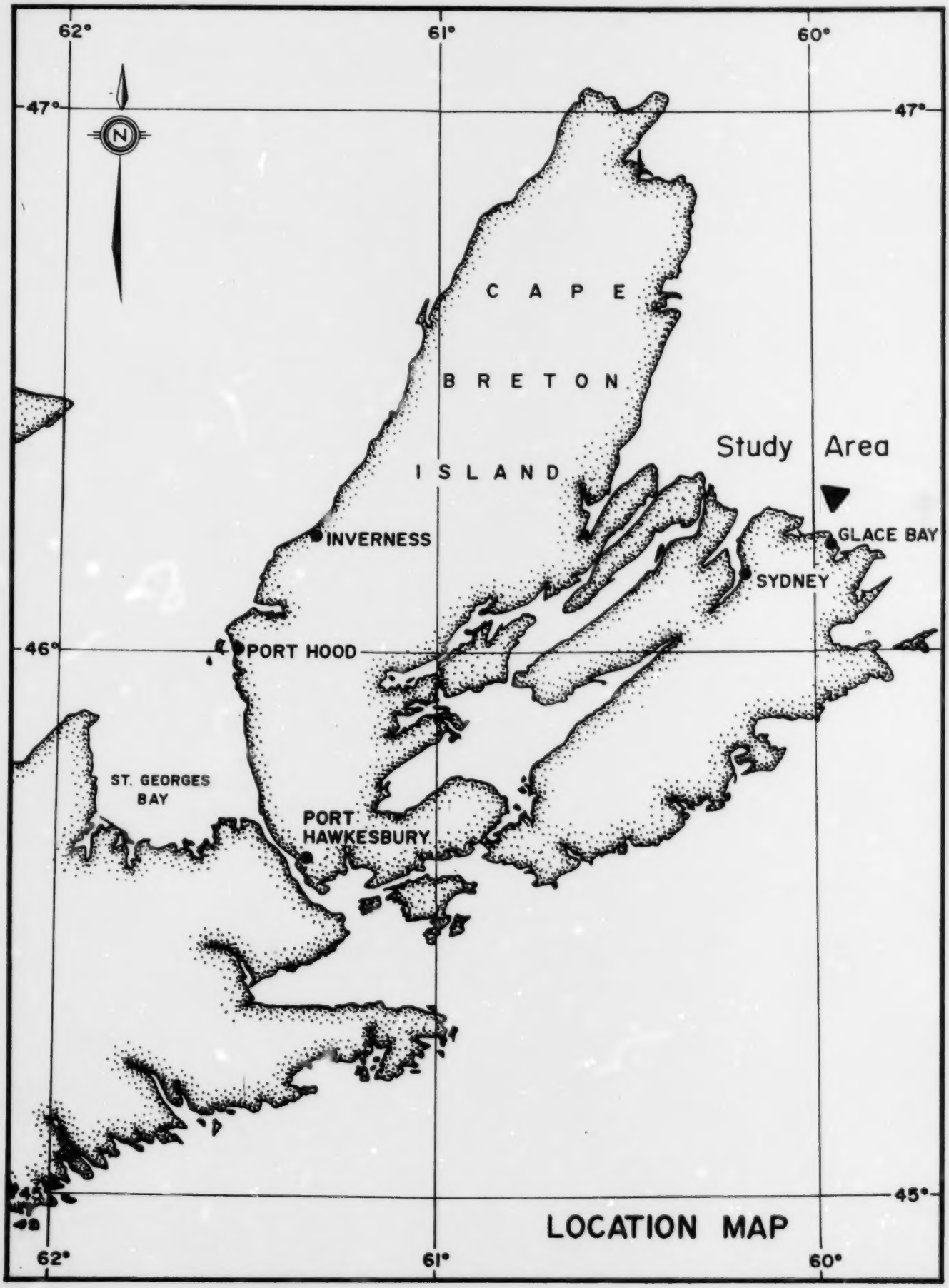

62°
61°
60°
47°
47°
N
CAPE
BRETON
ISLAND
Study Area
INVERNESS
GLACE BAY
SYDNEY
46°
PORT HOOD
ST. GEORGES
BAY
PORT
HAWKESBURY
45°
45°
LOCATION MAP
62°
61°
60°

FIGURE 1

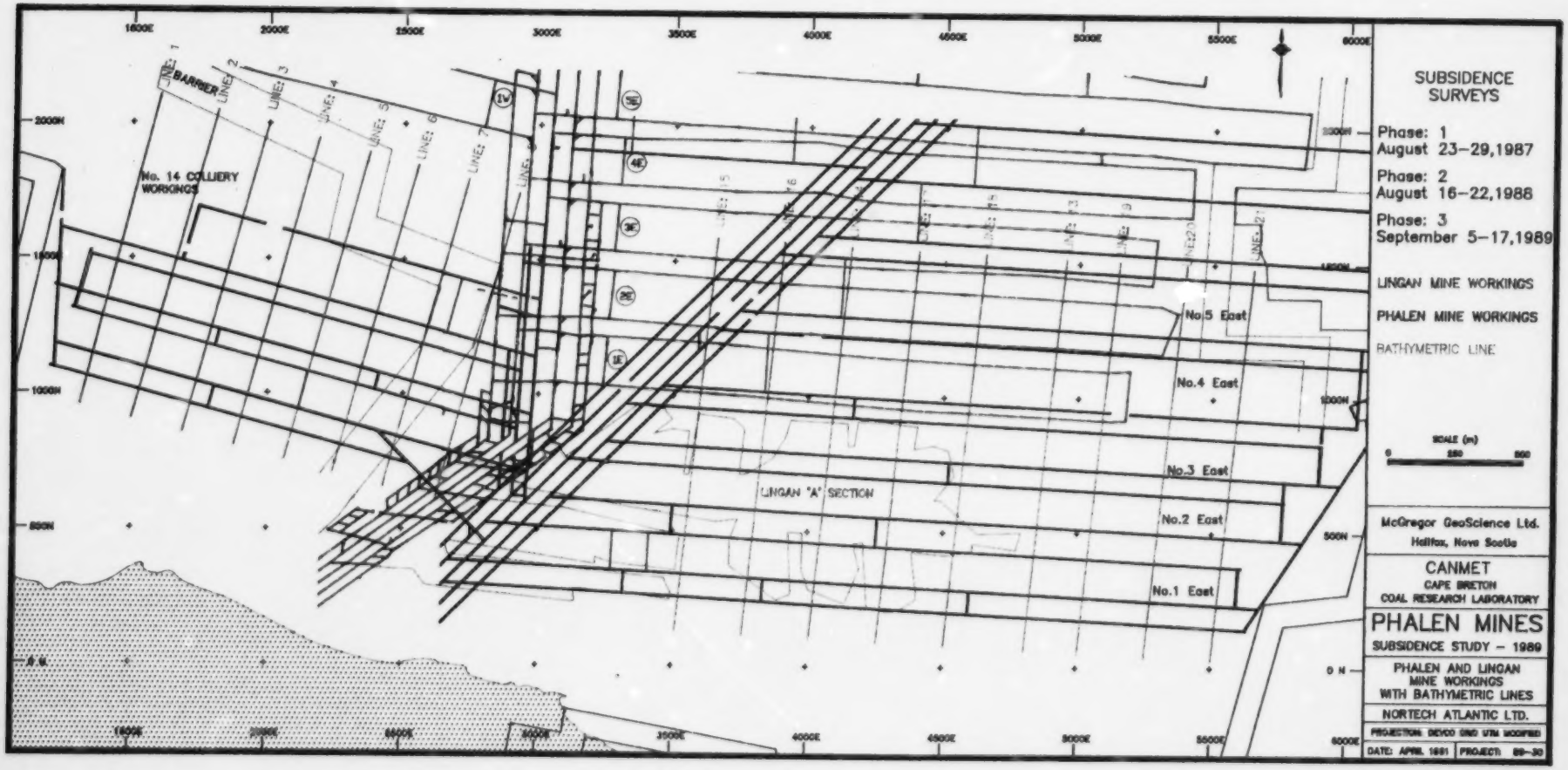

1500E
2000E
2500E
3000E
3500E
4000E
4500E
5000E
5500E
6000E
2000N
1500N
1000N
500N
0 N
BARRIER
LINE: 1
LINE: 2
LINE: 3
LINE: 4
LINE: 5
LINE: 6
LINE: 7
LINE: 8
LINE: 9
LINE: 10
LINE: 11
LINE: 12
LINE: 13
LINE: 14
LINE: 15
LINE: 16
LINE: 17
LINE: 18
LINE: 19
LINE: 20
LINE: 21
1W
5E
4E
3E
2E
1E
No. 14 COLLIERY WORKINGS
No.5 East
No.4 East
No.3 East
No.2 East
No.1 East
LINGAN "A" SECTION
SUBSIDENCE SURVEYS
Phase: 1
August 23-29,1987
Phase: 2
August 16-22,1988
Phase: 3
September 5-17,1989
LINGAN MINE WORKINGS
PHALEN MINE WORKINGS
BATHYMETRIC LINE
SCALE (m)
0
250
500
McGregor GeoScience Ltd.
Halifax, Nova Scotia
CANMET
CAPE BRETON
COAL RESEARCH LABORATORY
PHALEN MINES
SUBSIDENCE STUDY - 1989
PHALEN AND LINGAN
MINE WORKINGS
WITH BATHYMETRIC LINES
NORTECH ATLANTIC LTD.
PROJECTION: DEVOO GRID UTM MODIFIED
DATE: APRIL 1991
PROJECT: 89-30

FIGURE 2

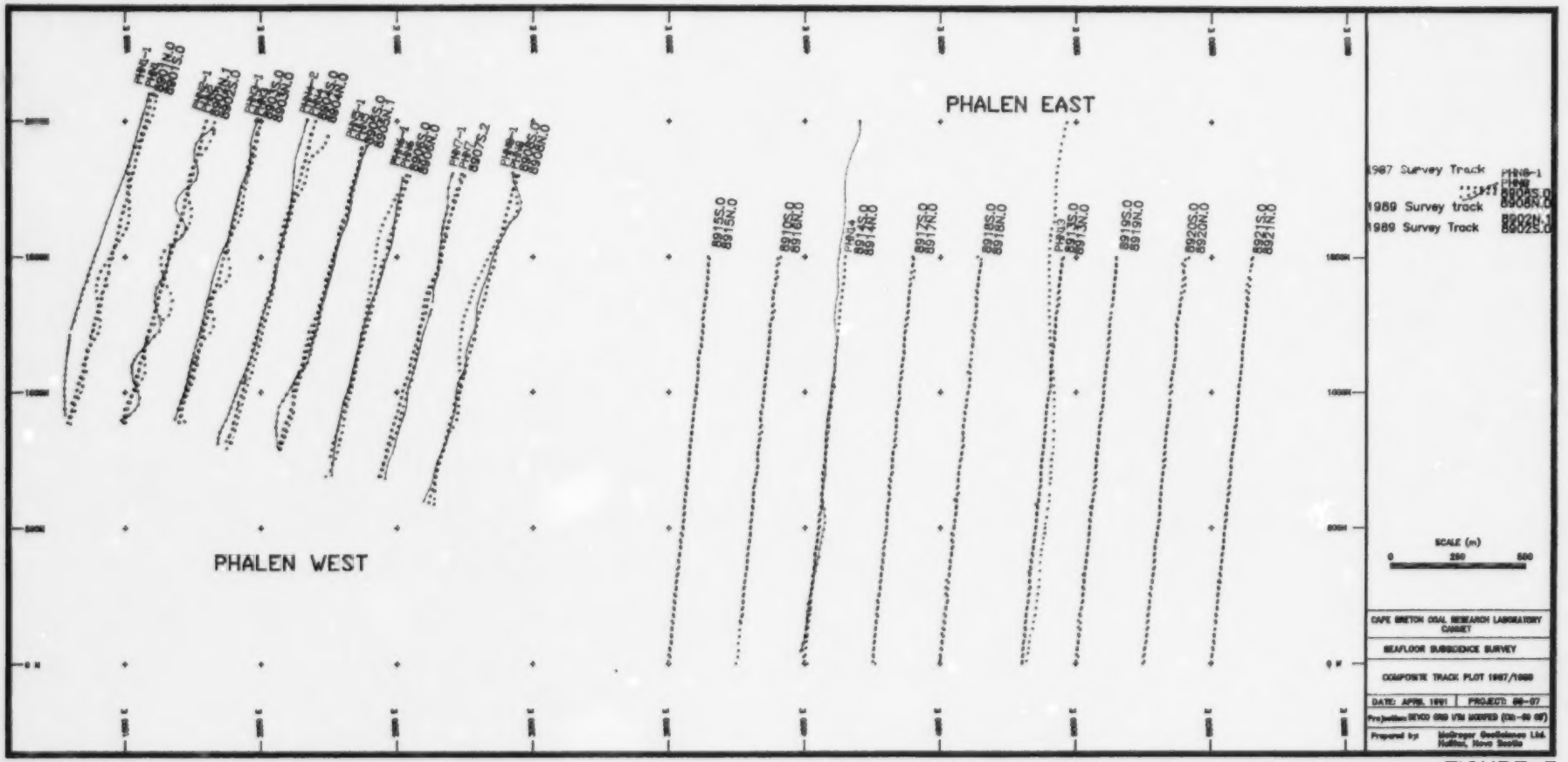

PHALEN EAST
PHALEN WEST
1987 Survey Track
1989 Survey track
1989 Survey Track
SCALE (m)
0
250
500
CAPE BRETON COAL RESEARCH LABORATORY CANMET
SEAFLOOR SUBSIDENCE SURVEY
COMPOSITE TRACK PLOT 1987/1989
DATE: APRIL 1991
PROJECT: 88-07
Prepared by McIntyre GeoScience Ltd. Halifax, Nova Scotia

FIGURE 3

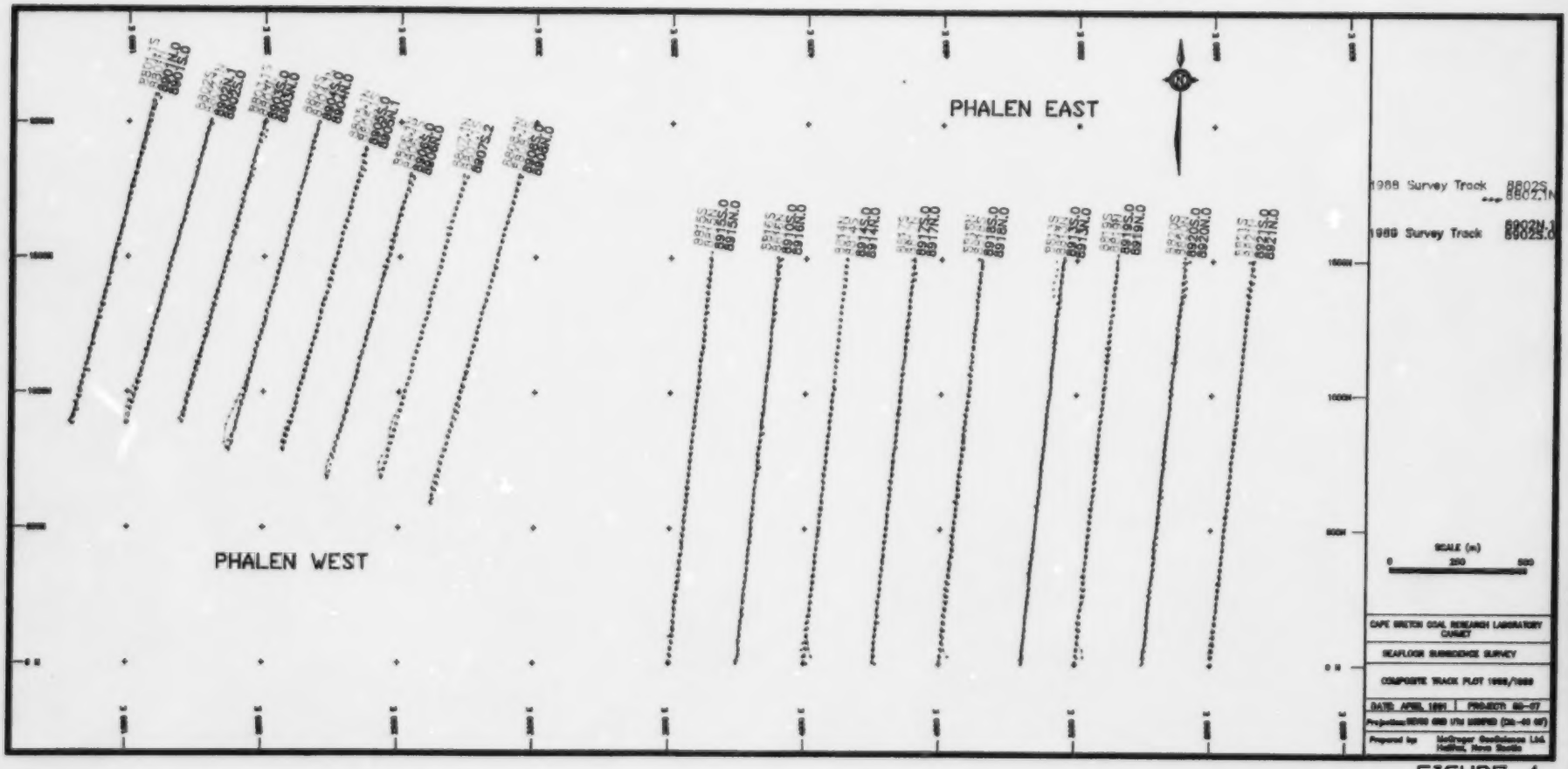

PHALEN EAST
PHALEN WEST
1988 Survey Track
1989 Survey Track
SCALE (m)
0
250
500
CAPE BRETON COAL RESEARCH LABORATORY CANMET
SEAFLOOR SUBSIDENCE SURVEY
COMPOSITE TRACK PLOT 1988/1989
DATE: APRIL 1991
PROJECT: 90-07
Prepared by: MacGregor GeoScience Ltd.
Halifax, Nova Scotia

FIGURE 4

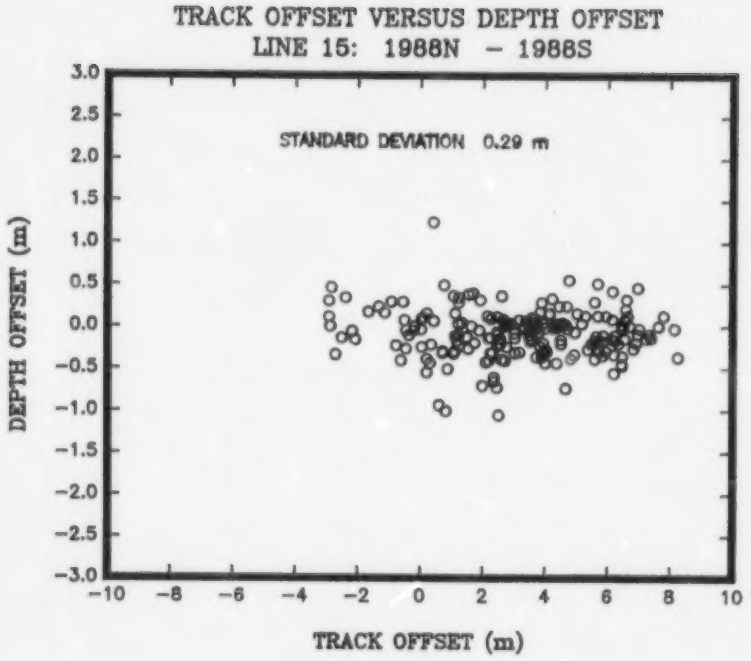


FIGURE 5

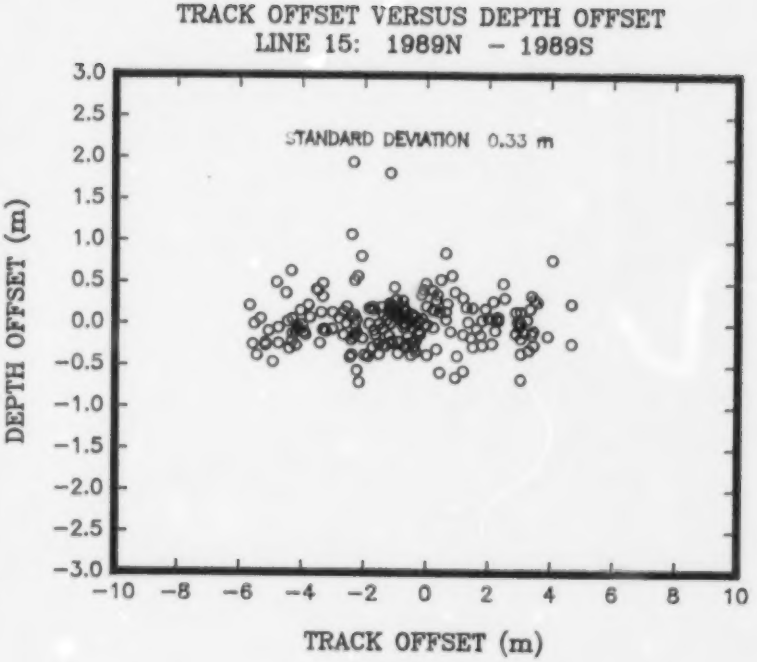


FIGURE 6

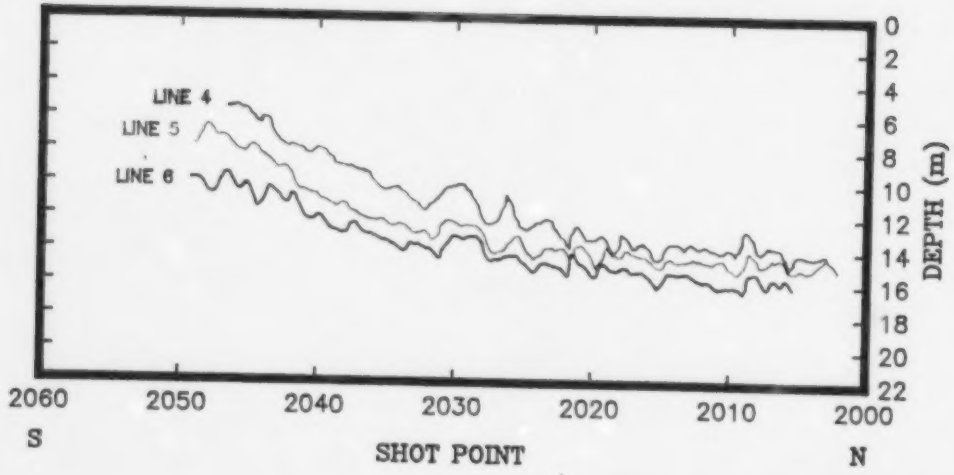


FIGURE 7

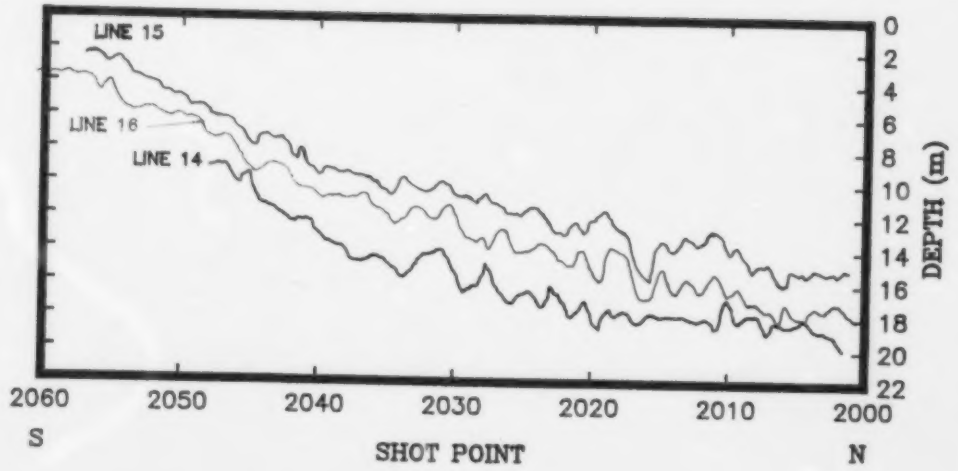
BATHYMETRIC PROFILES
FROM LINES: 4, 5, AND 6

NOTE: Vertical shifts have been applied to enhance the correlation between profiles.

FIGURE 8

BATHYMETRIC PROFILES
FROM LINES: 14, 15, AND 16

NOTE: Vertical shifts have been applied to enhance the correlation between profiles.



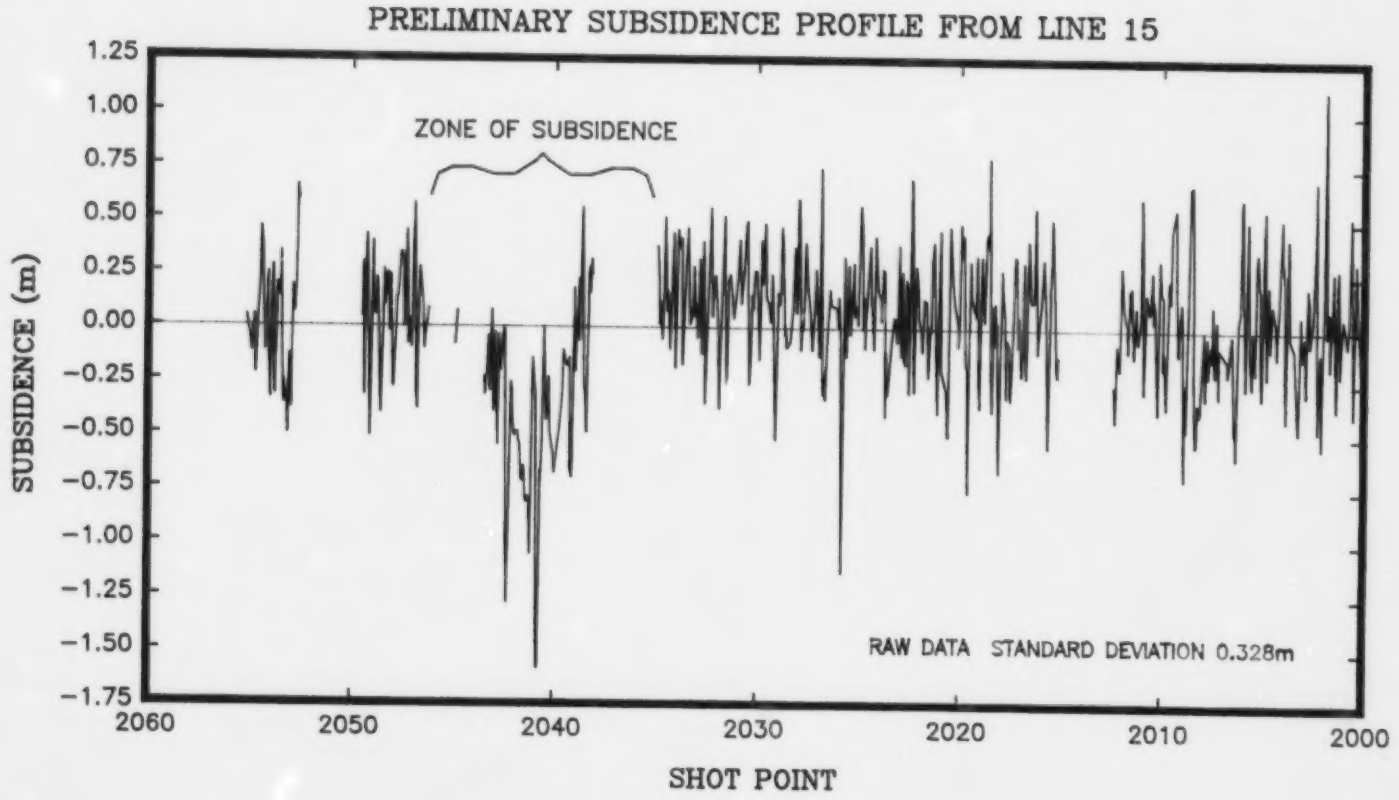

PRELIMINARY SUBSIDENCE PROFILE FROM LINE 15
ZONE OF SUBSIDENCE
RAW DATA STANDARD DEVIATION 0.328m
SUBSIDENCE (m)
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
−1.25
−1.50
−1.75
2060
2050
2040
2030
2020
2010
2000
SHOT POINT

FIGURE 9

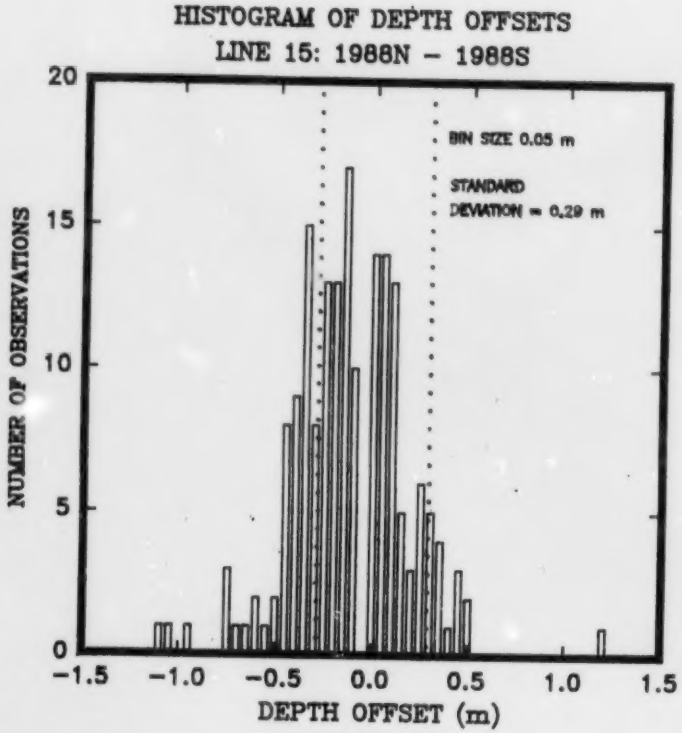


FIGURE 10

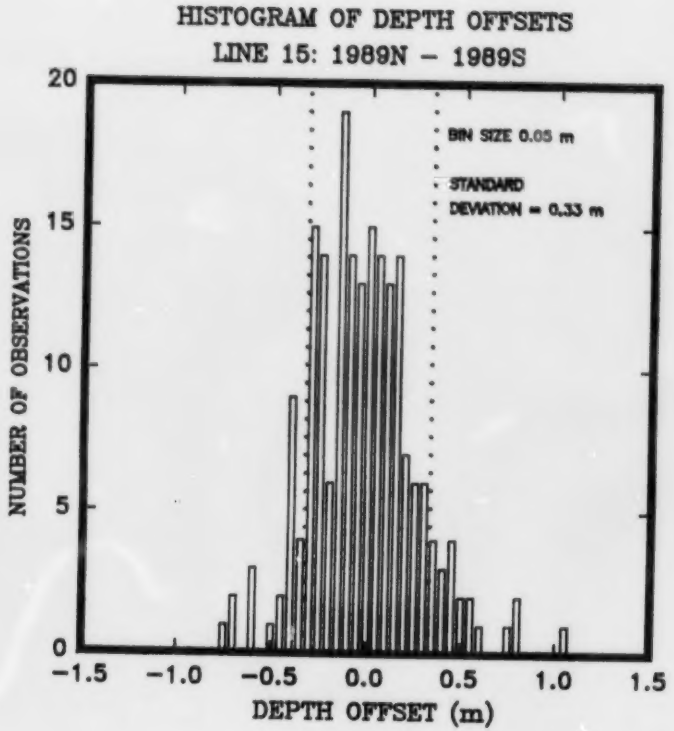


FIGURE 11

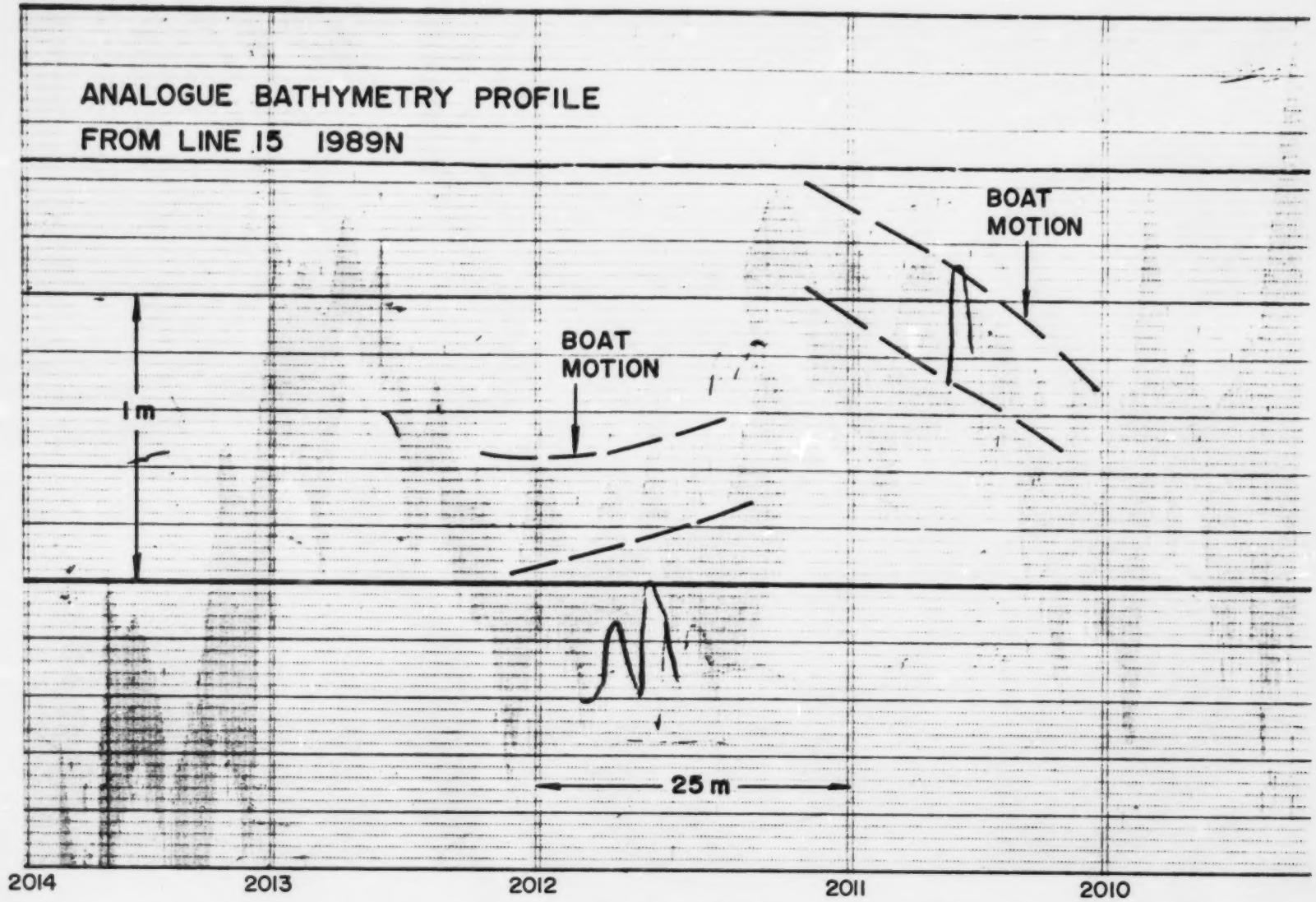

ANALOGUE BATHYMETRY PROFILE
FROM LINE 15 1989N
BOAT MOTION
BOAT MOTION
1m
25 m
2014
2013
2012
2011
2010
SHOT POINT

FIGURE 12

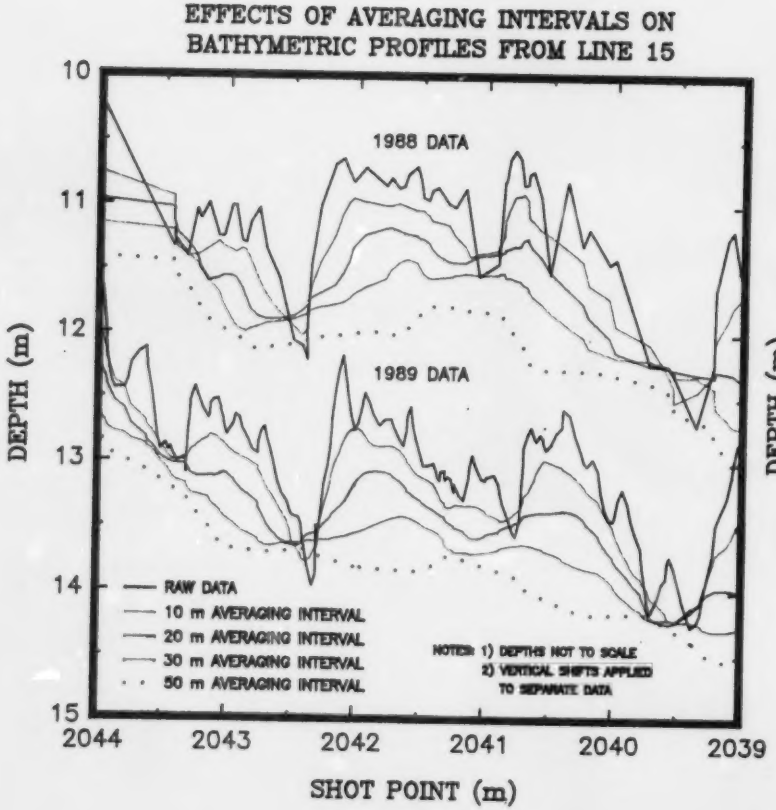


FIGURE 13

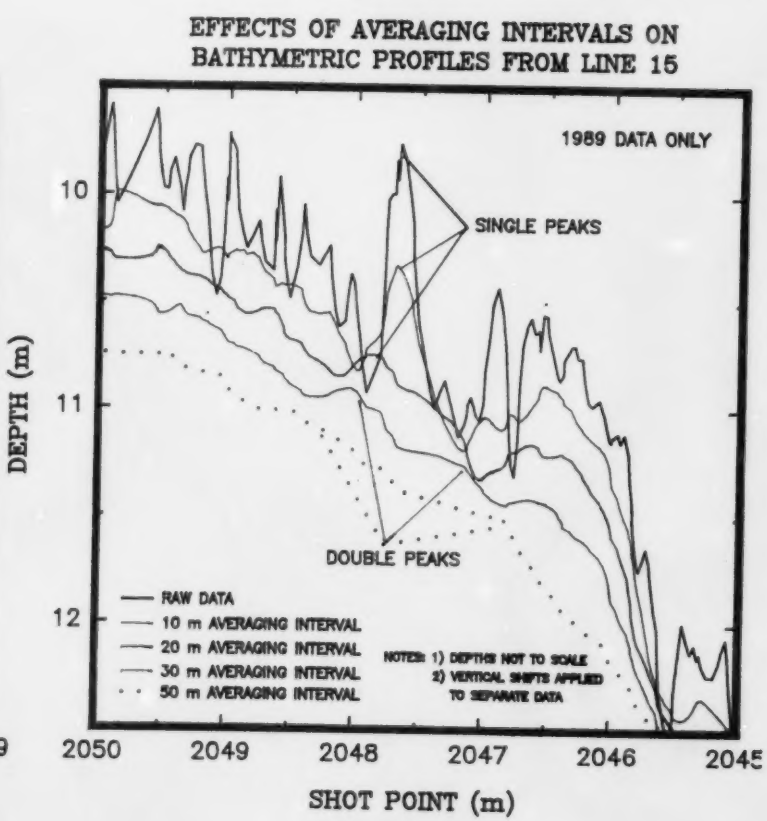


FIGURE 14

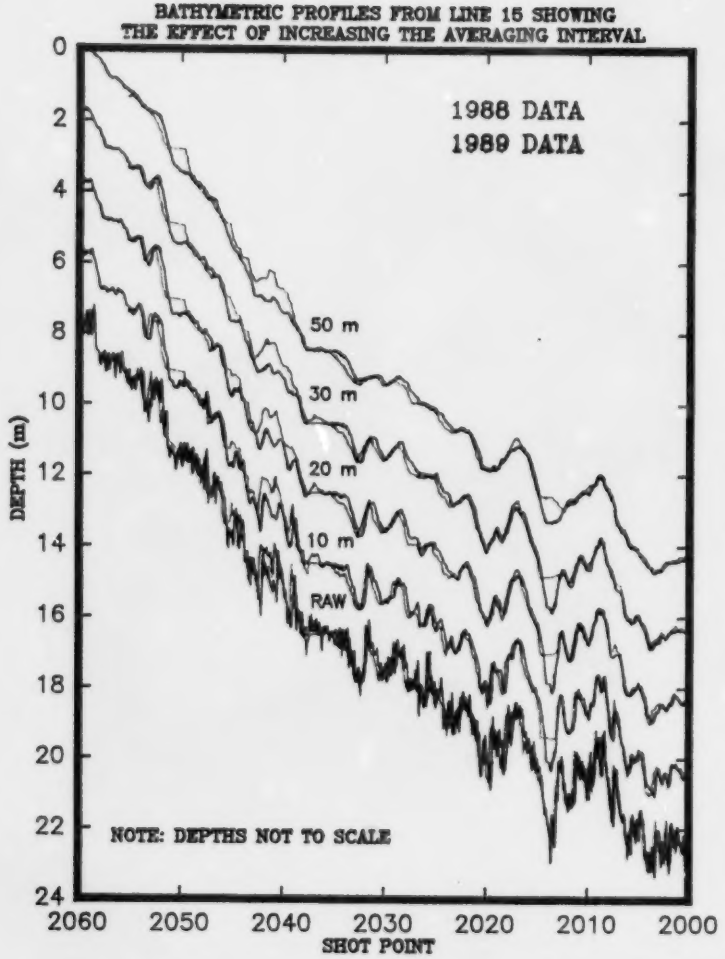


FIGURE 15

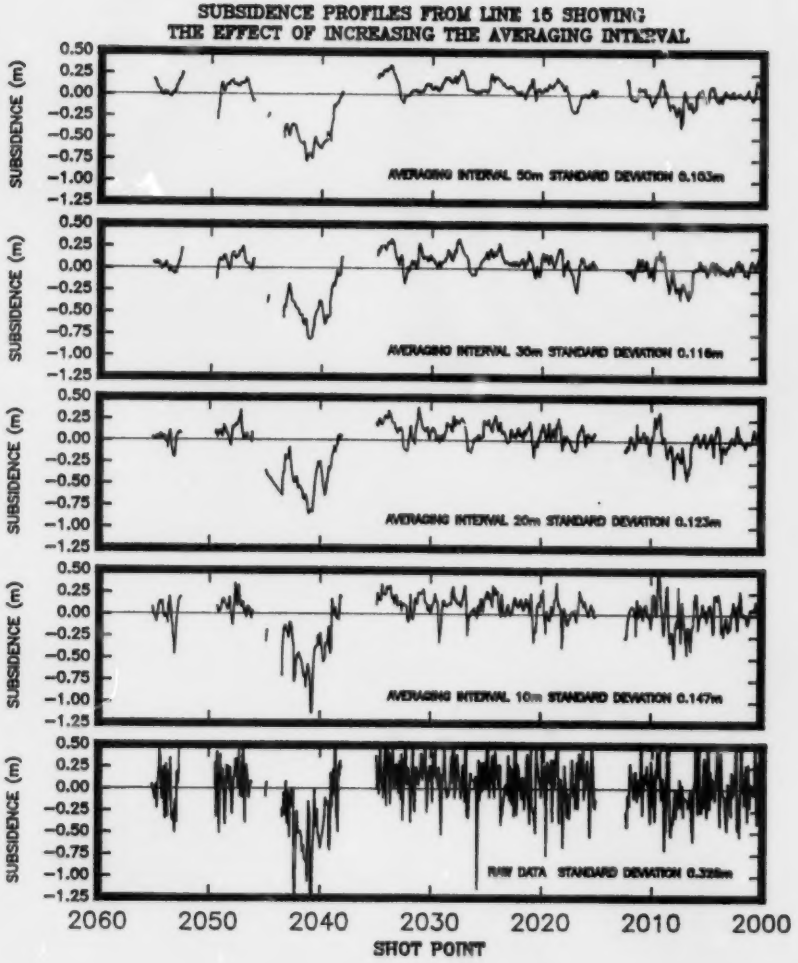


FIGURE 16

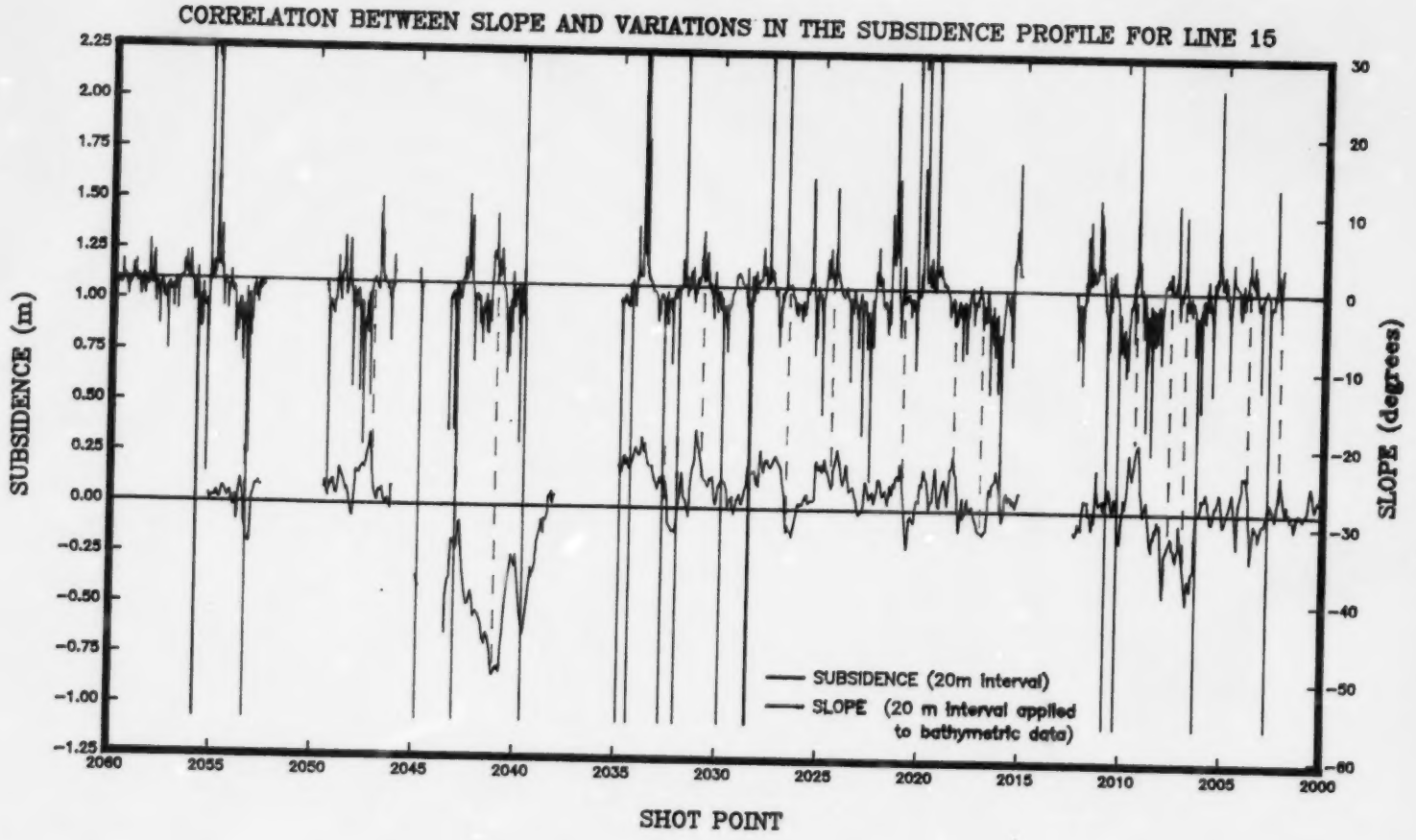

CORRELATION BETWEEN SLOPE AND VARIATIONS IN THE SUBSIDENCE PROFILE FOR LINE 15
SUBSIDENCE (m)
SLOPE (degrees)
SHOT POINT
SUBSIDENCE (20m interval)
SLOPE (20 m interval applied to bathymetric data)
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
30
20
10
0
-10
-20
-30
-40
-50
-60
2060
2055
2050
2045
2040
2035
2030
2025
2020
2015
2010
2005
2000

FIGURE 17

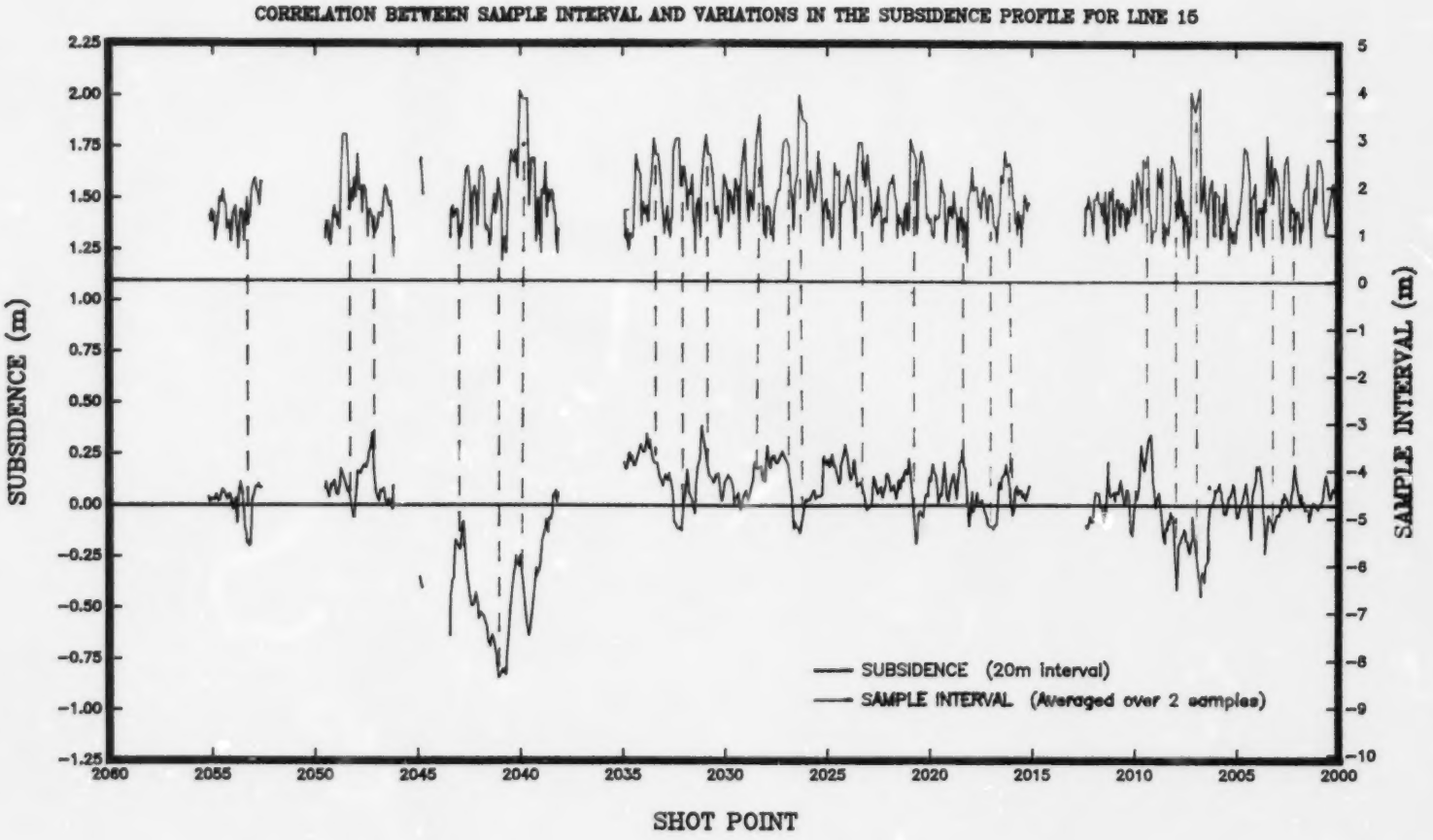

CORRELATION BETWEEN SAMPLE INTERVAL AND VARIATIONS IN THE SUBSIDENCE PROFILE FOR LINE 15
SUBSIDENCE (m)
SAMPLE INTERVAL (m)
SHOT POINT
SUBSIDENCE (20m interval)
SAMPLE INTERVAL (Averaged over 2 samples)

FIGURE 18

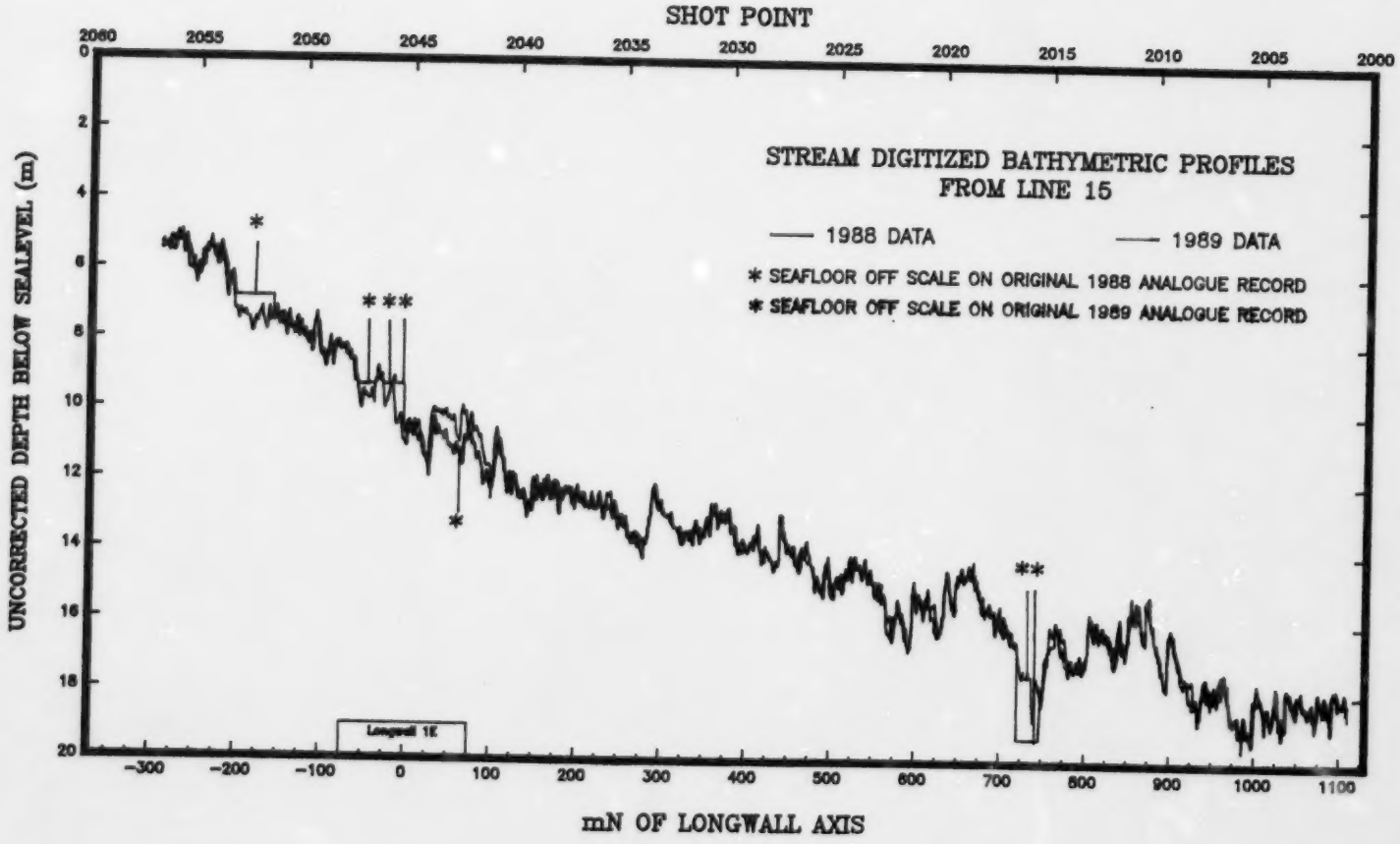

SHOT POINT
2060
2055
2050
2045
2040
2035
2030
2025
2020
2015
2010
2005
2000
STREAM DIGITIZED BATHYMETRIC PROFILES
FROM LINE 15
1988 DATA
1989 DATA
* SEAFLOOR OFF SCALE ON ORIGINAL 1988 ANALOGUE RECORD
* SEAFLOOR OFF SCALE ON ORIGINAL 1989 ANALOGUE RECORD
UNCORRECTED DEPTH BELOW SEALEVEL (m)
0
2
4
6
8
10
12
14
16
18
20
Longwall 1E
-300
-200
-100
0
100
200
300
400
500
600
700
800
900
1000
1100
mN OF LONGWALL AXIS

FIGURE 19

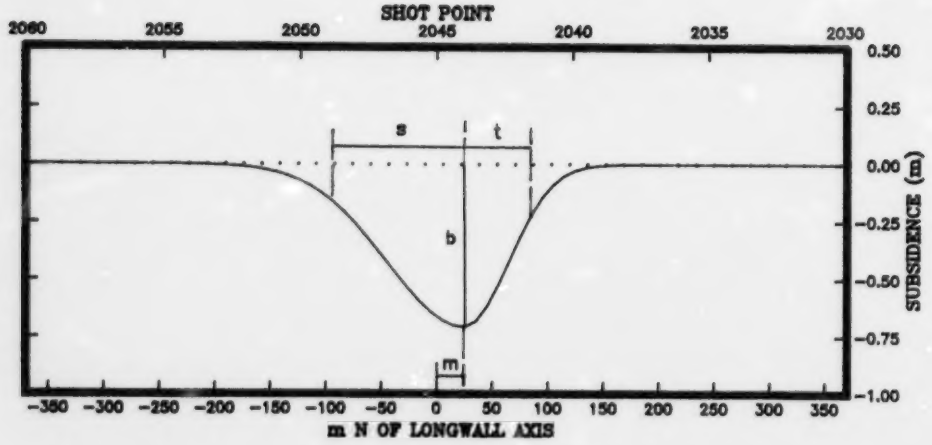


FIGURE 20

AN IDEALIZED SUBSIDENCE PROFILE
SHOWING THE CONSTANTS IN EQUATION 1

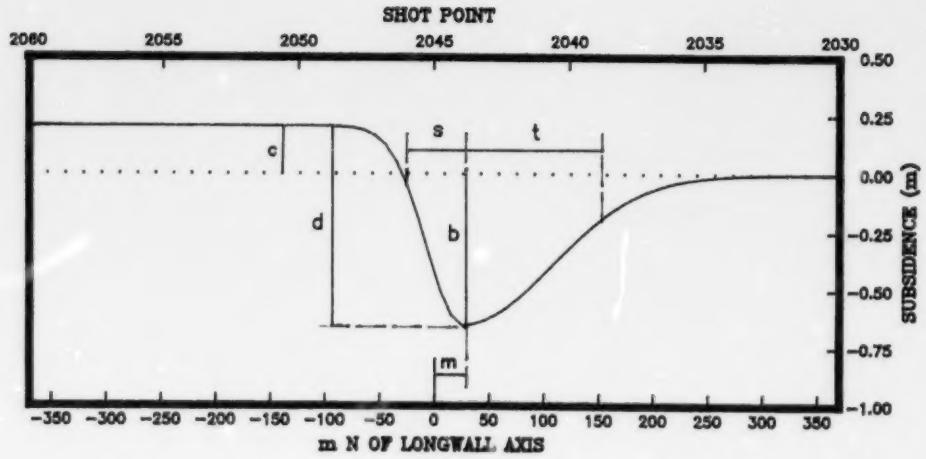


FIGURE 21

AN IDEALIZED SUBSIDENCE PROFILE
SHOWING THE CONSTANTS IN EQUATION 2

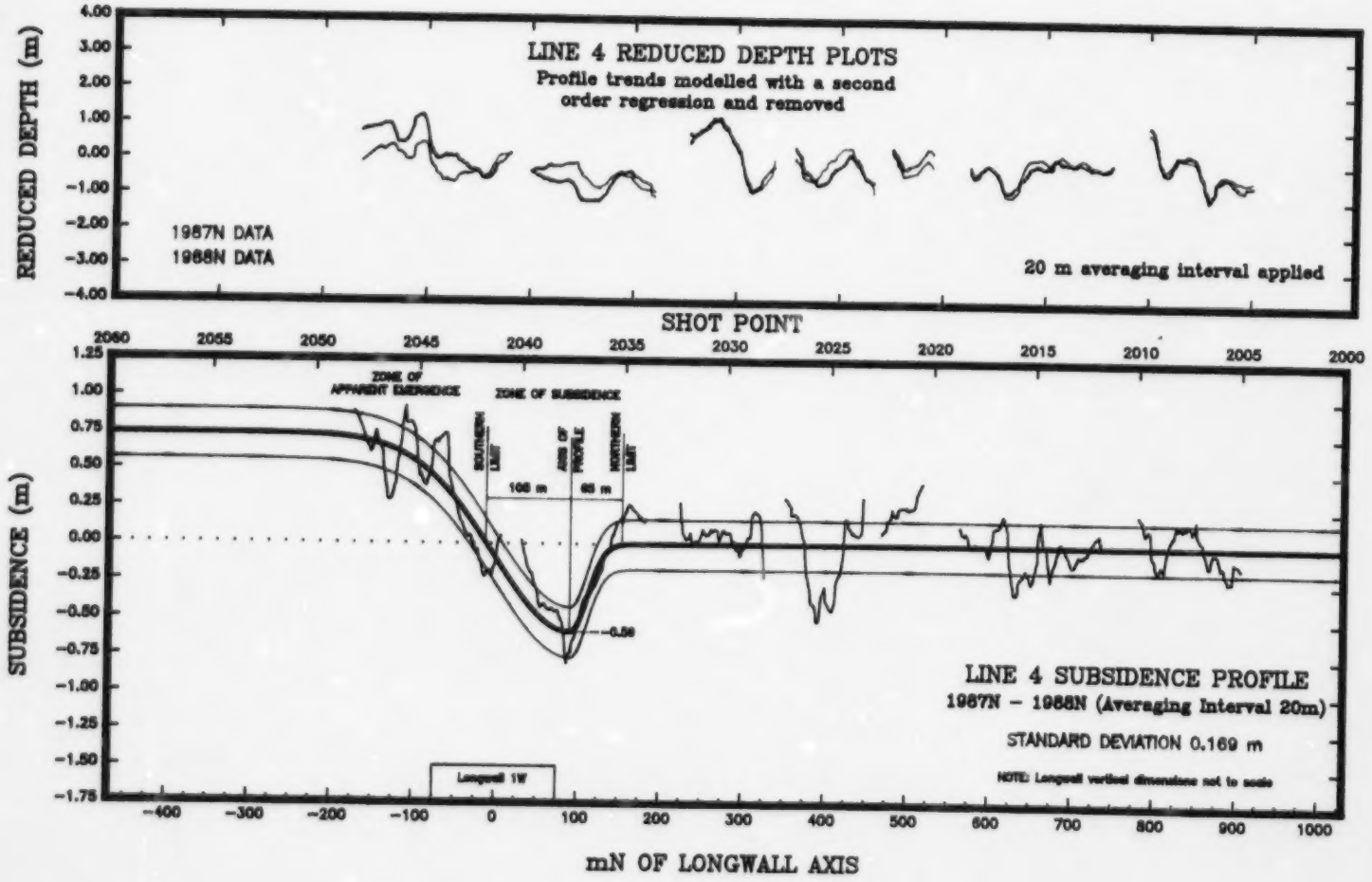

LINE 4 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
REDUCED DEPTH (m)
1987N DATA
1988N DATA
20 m averaging interval applied
SHOT POINT
SUBSIDENCE (m)
ZONE OF APPARENT EMERGENCE
ZONE OF SUBSIDENCE
SOUTHERN LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
100 m
65 m
-0.56
LINE 4 SUBSIDENCE PROFILE
1987N - 1988N (Averaging Interval 20m)
STANDARD DEVIATION 0.169 m
Longwall 1W
mN OF LONGWALL AXIS

FIGURE 22

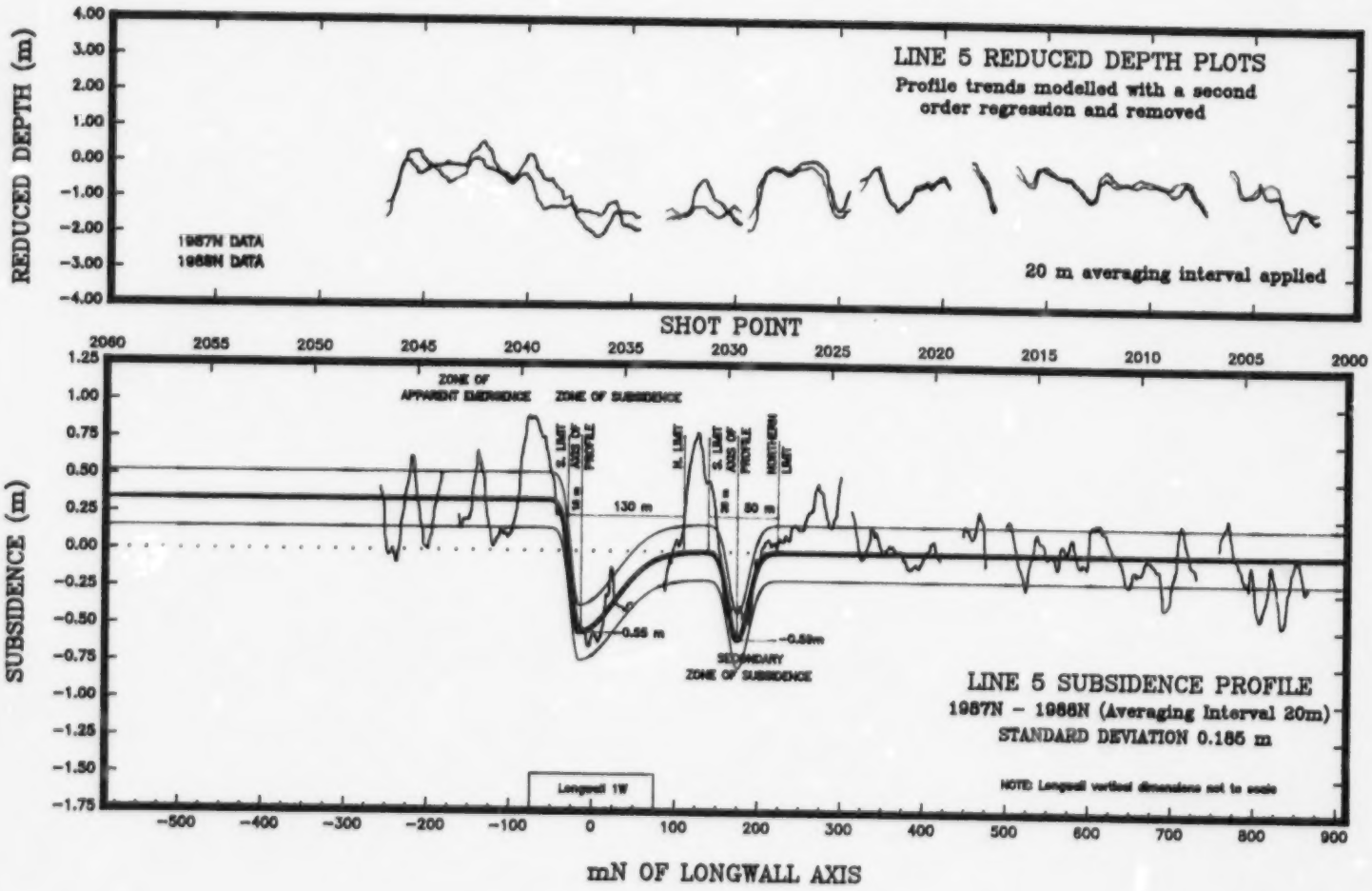

LINE 5 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
1987N DATA
1988N DATA
20 m averaging interval applied
REDUCED DEPTH (m)
SHOT POINT
ZONE OF APPARENT EMERGENCE
ZONE OF SUBSIDENCE
130 m
80 m
0.55 m
-0.58m
SECONDARY ZONE OF SUBSIDENCE
LINE 5 SUBSIDENCE PROFILE
1987N - 1988N (Averaging Interval 20m)
STANDARD DEVIATION 0.165 m
Longwall 1W
SUBSIDENCE (m)
mN OF LONGWALL AXIS

FIGURE 23

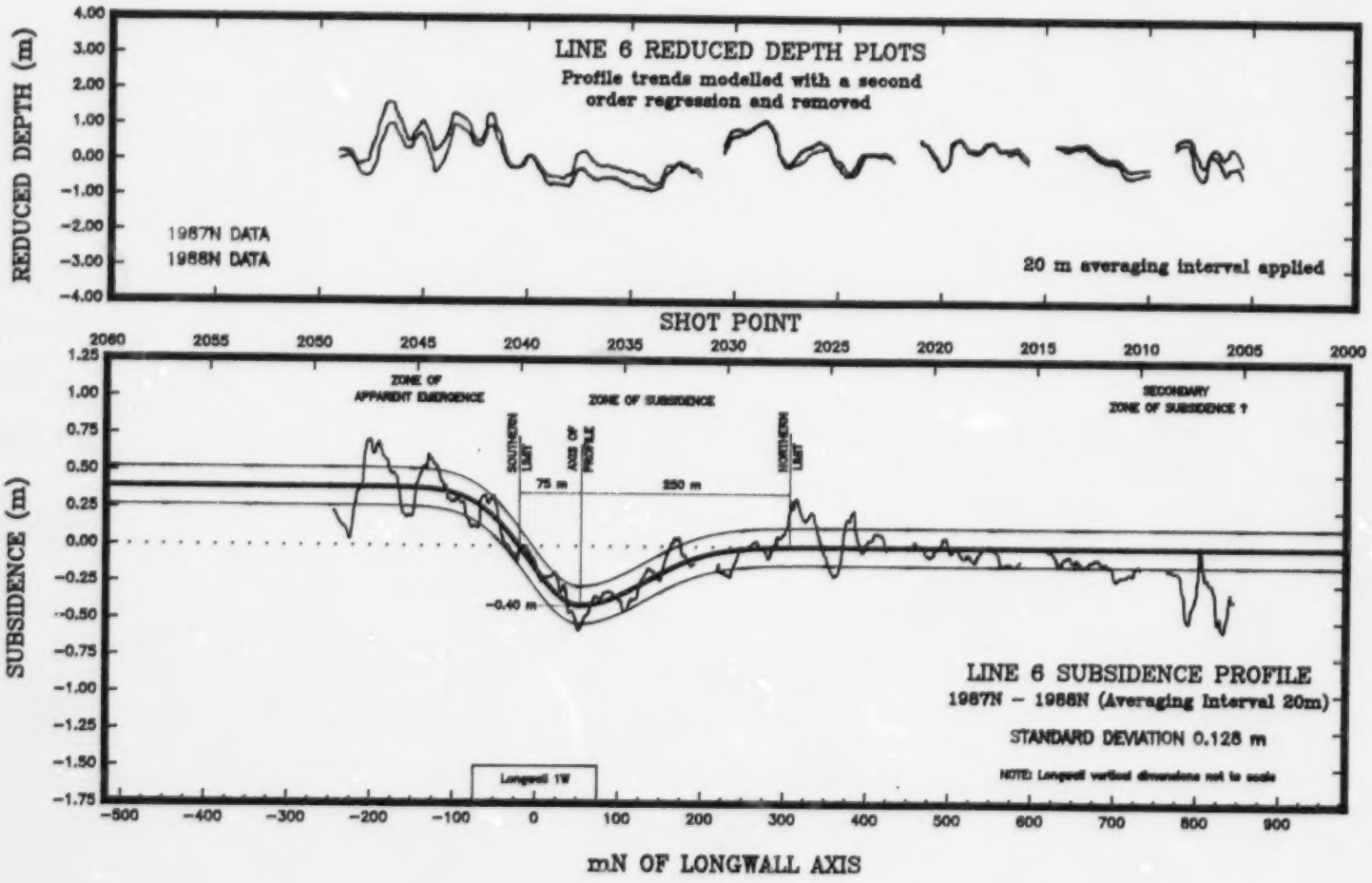

LINE 6 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
REDUCED DEPTH (m)
1987N DATA
1988N DATA
20 m averaging interval applied
SHOT POINT
ZONE OF APPARENT EMERGENCE
ZONE OF SUBSIDENCE
SECONDARY ZONE OF SUBSIDENCE ?
SOUTHERN LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
75 m
250 m
-0.40 m
SUBSIDENCE (m)
LINE 6 SUBSIDENCE PROFILE
1987N – 1988N (Averaging Interval 20m)
STANDARD DEVIATION 0.128 m
Longwall 1W
mN OF LONGWALL AXIS

FIGURE 24

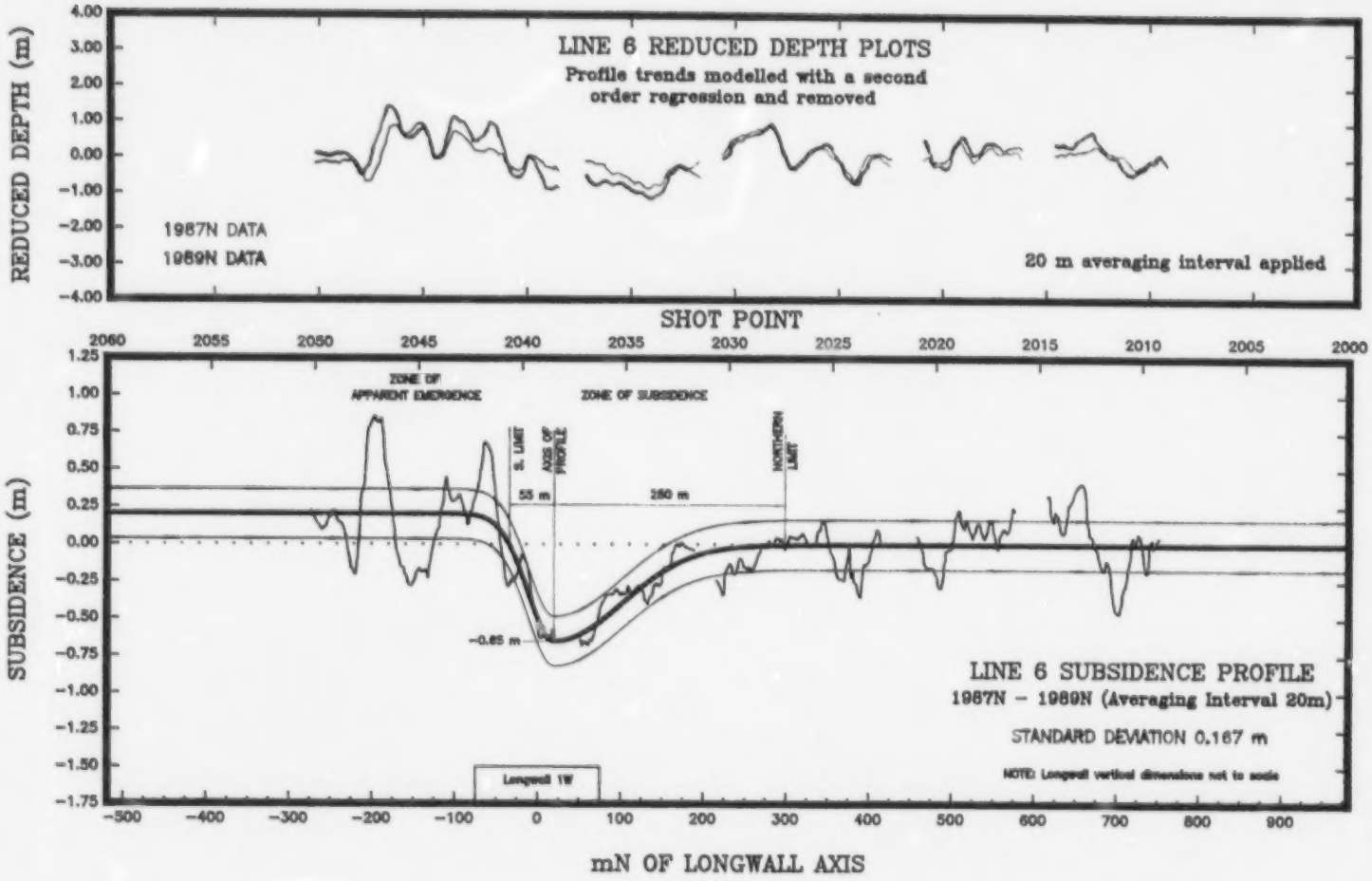

LINE 6 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
1987N DATA
1989N DATA
20 m averaging interval applied
REDUCED DEPTH (m)
SHOT POINT
ZONE OF APPARENT EMERGENCE
ZONE OF SUBSIDENCE
S. LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
55 m
250 m
-0.65 m
LINE 6 SUBSIDENCE PROFILE
1987N - 1989N (Averaging Interval 20m)
STANDARD DEVIATION 0.167 m
NOTE: Longwall vertical dimensions not to scale
Longwall 1W
SUBSIDENCE (m)
mN OF LONGWALL AXIS

FIGURE 25

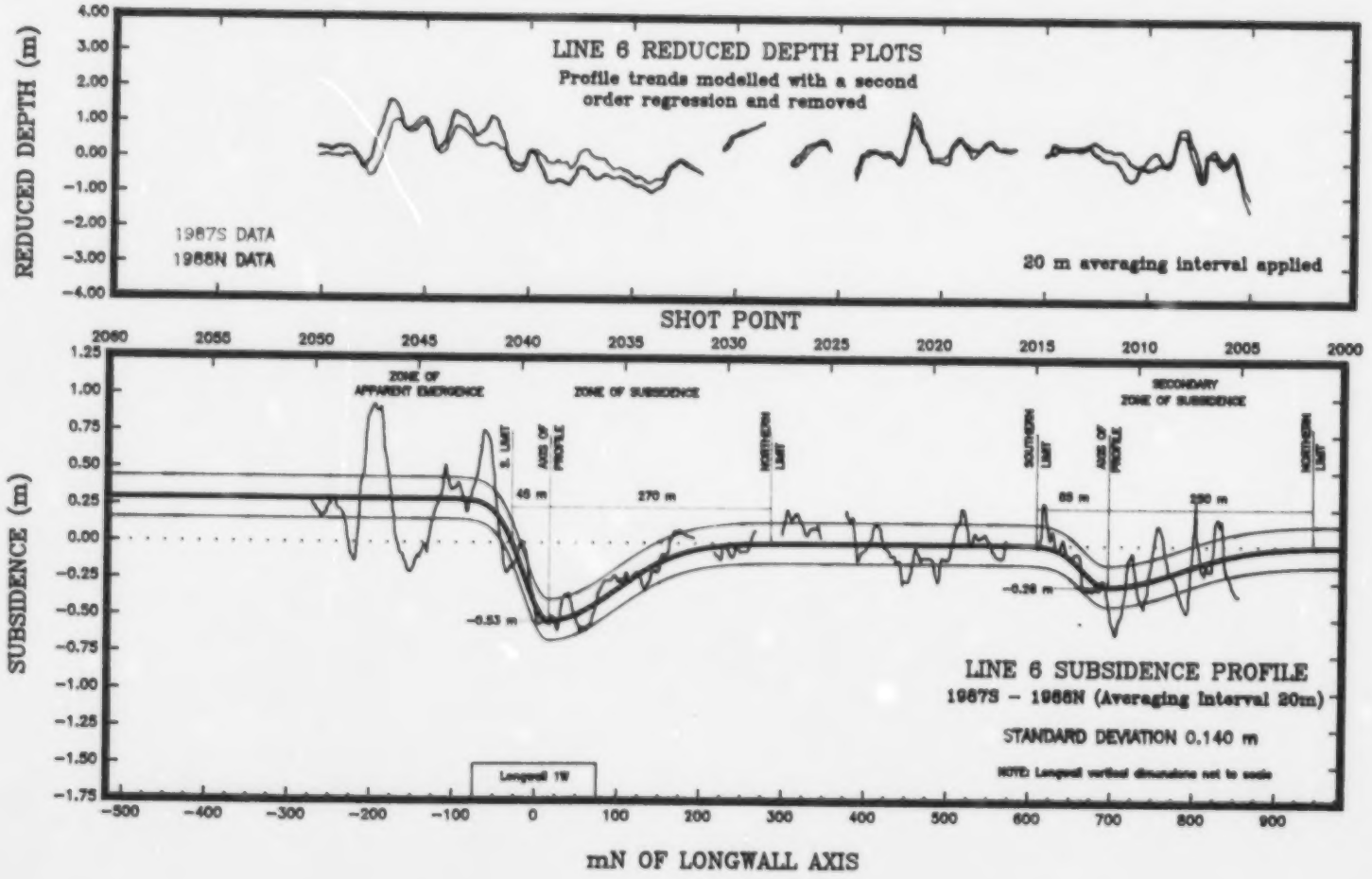

LINE 6 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
REDUCED DEPTH (m)
1987S DATA
1988N DATA
20 m averaging interval applied
SHOT POINT
ZONE OF APPARENT EMERGENCE
ZONE OF SUBSIDENCE
SECONDARY ZONE OF SUBSIDENCE
S. LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
SOUTHERN LIMIT
45 m
270 m
85 m
280 m
-0.53 m
-0.26 m
LINE 6 SUBSIDENCE PROFILE
1987S – 1988N (Averaging Interval 20m)
STANDARD DEVIATION 0.140 m
Longwall 1W
SUBSIDENCE (m)
mN OF LONGWALL AXIS

FIGURE 26

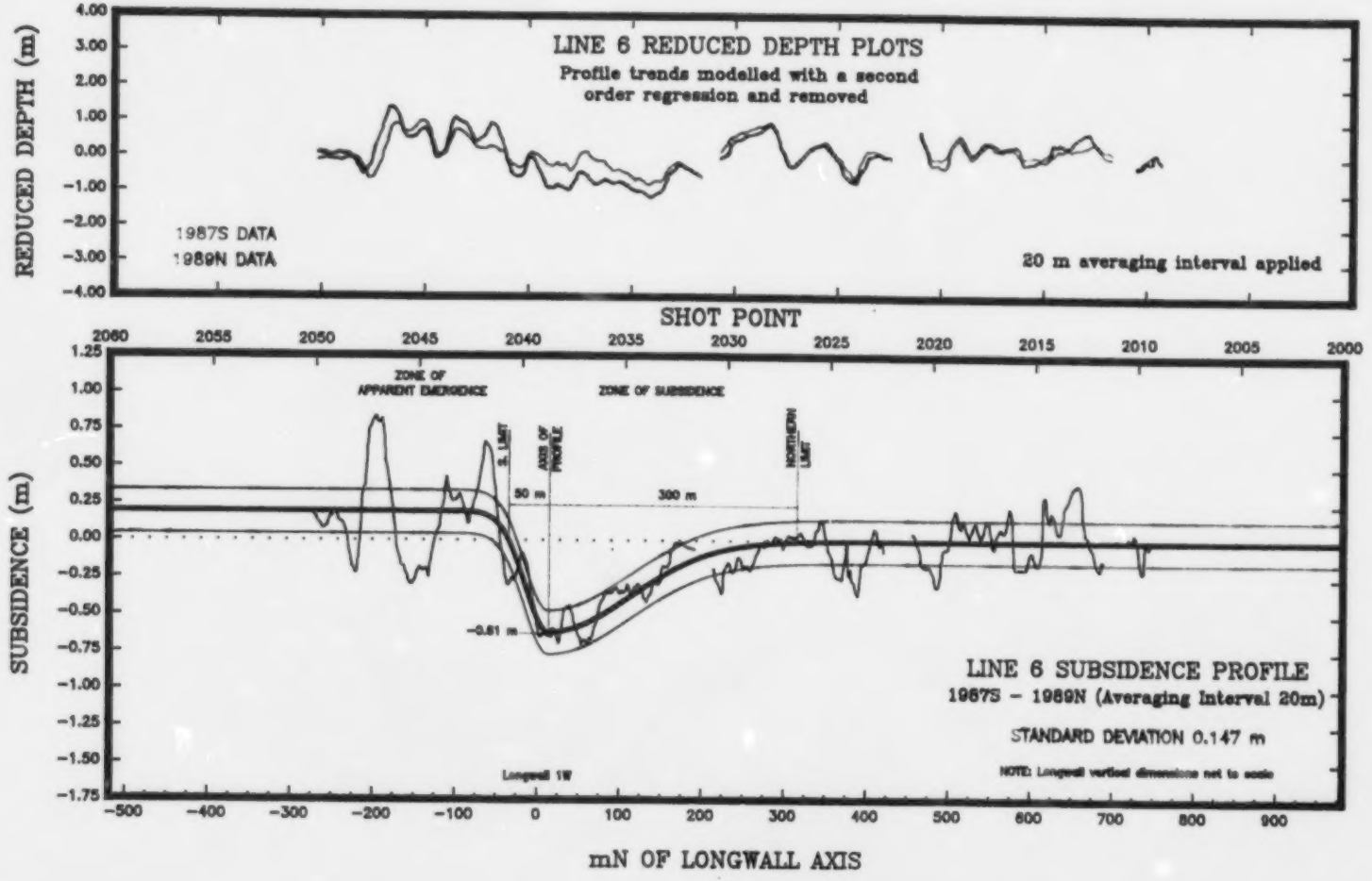

LINE 6 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
REDUCED DEPTH (m)
1987S DATA
1989N DATA
20 m averaging interval applied
SHOT POINT
ZONE OF APPARENT EMERGENCE
ZONE OF SUBSIDENCE
S. LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
50 m
300 m
-0.61 m
SUBSIDENCE (m)
LINE 6 SUBSIDENCE PROFILE
1987S - 1989N (Averaging Interval 20m)
STANDARD DEVIATION 0.147 m
Longwall 1W
mN OF LONGWALL AXIS

FIGURE 27

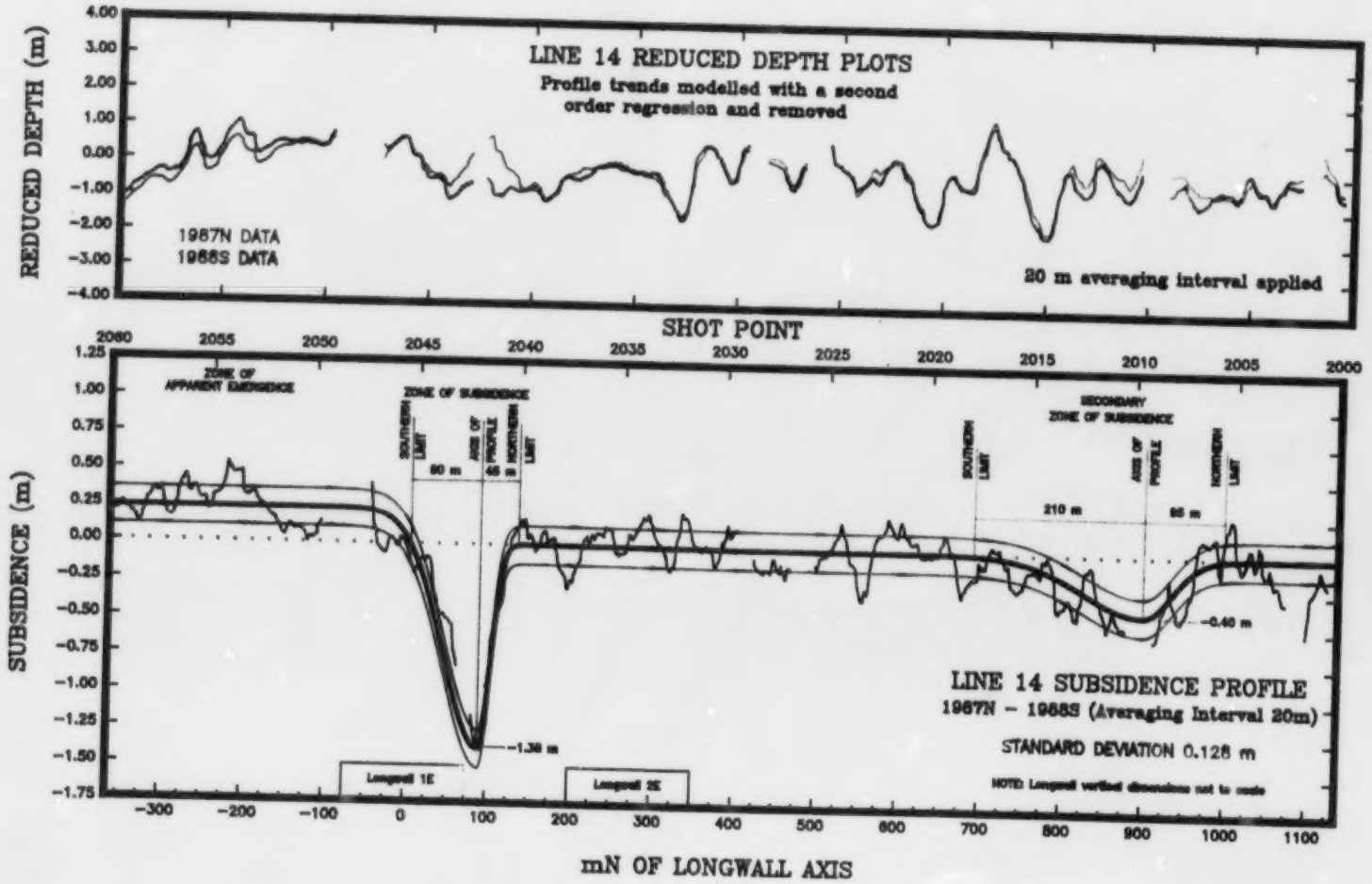

LINE 14 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
REDUCED DEPTH (m)
1987N DATA
1988S DATA
20 m averaging interval applied
SHOT POINT
SUBSIDENCE (m)
ZONE OF APPARENT EMERGENCE
ZONE OF SUBSIDENCE
SECONDARY ZONE OF SUBSIDENCE
SOUTHERN LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
80 m
45 m
210 m
95 m
-1.36 m
-0.40 m
Longwall 1E
Longwall 2E
LINE 14 SUBSIDENCE PROFILE
1987N – 1988S (Averaging Interval 20m)
STANDARD DEVIATION 0.128 m
mN OF LONGWALL AXIS

FIGURE 28

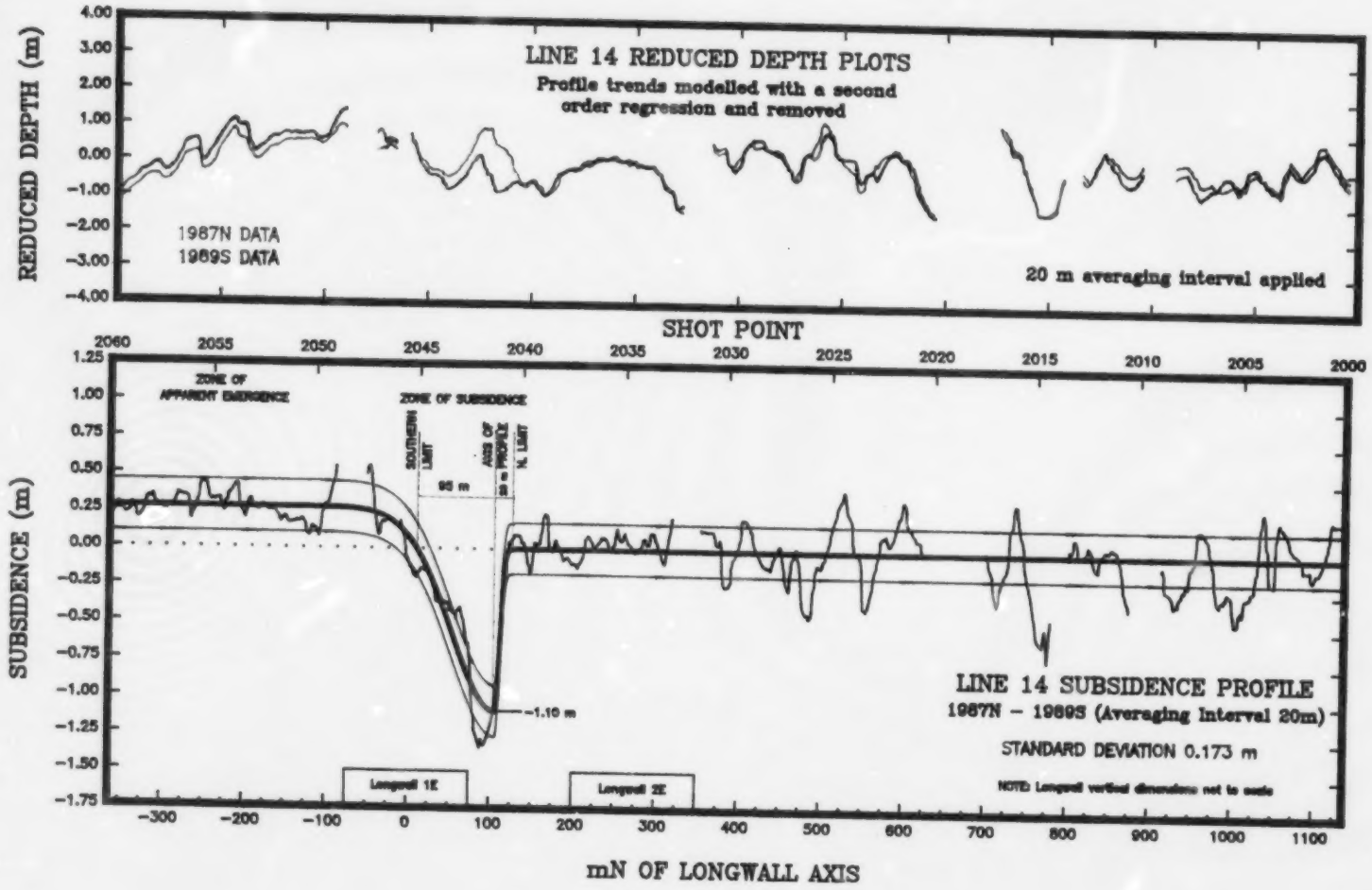

LINE 14 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
REDUCED DEPTH (m)
1987N DATA
1989S DATA
20 m averaging interval applied
SHOT POINT
SUBSIDENCE (m)
ZONE OF APPARENT EMERGENCE
ZONE OF SUBSIDENCE
SOUTHERN LIMIT
AXIS OF 20 m PROFILE
N. LIMIT
95 m
-1.10 m
LINE 14 SUBSIDENCE PROFILE
1987N - 1989S (Averaging Interval 20m)
STANDARD DEVIATION 0.173 m
Longwall 1E
Longwall 2E
mN OF LONGWALL AXIS

FIGURE 29

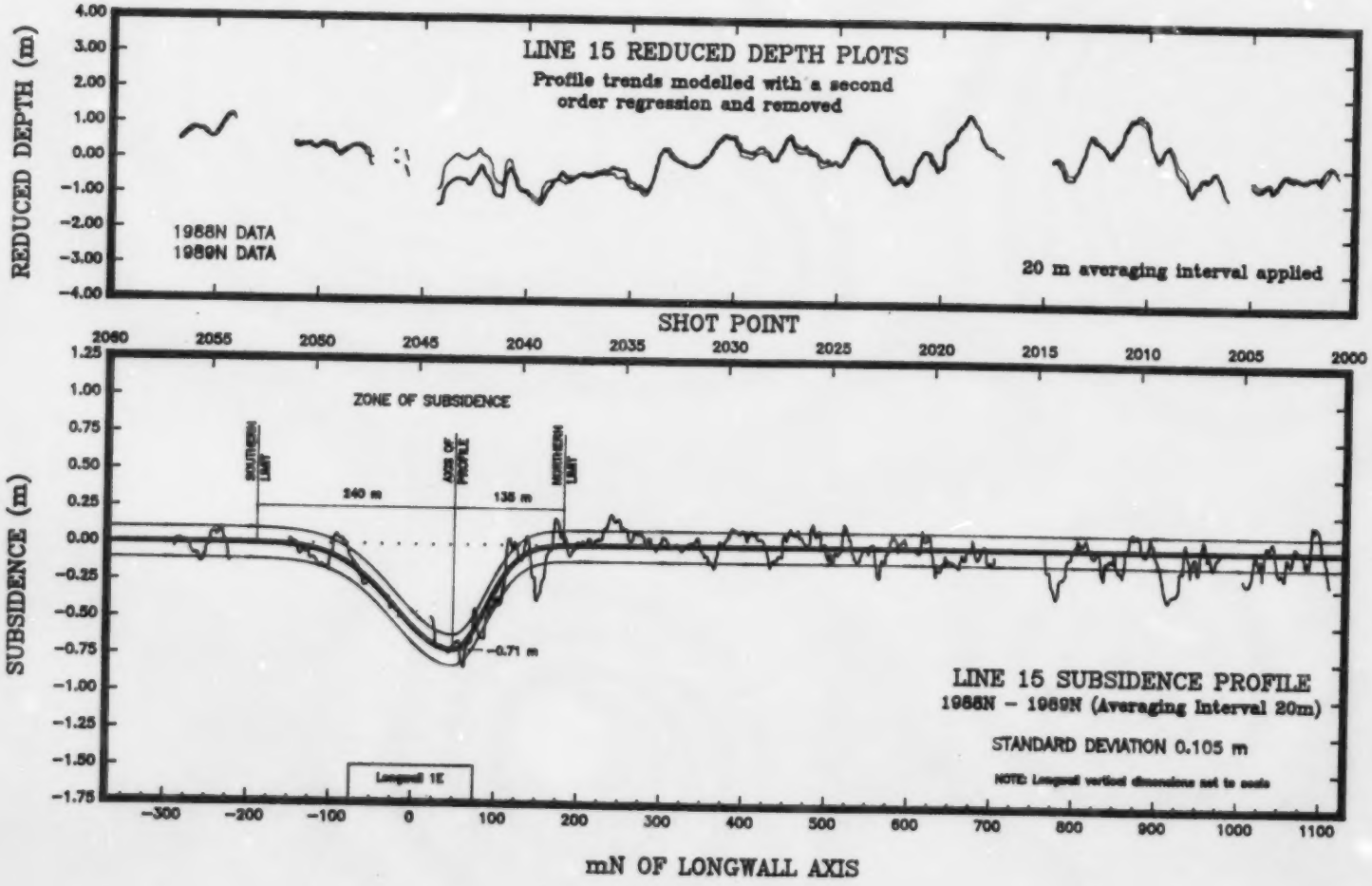

LINE 15 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
REDUCED DEPTH (m)
1988N DATA
1989N DATA
20 m averaging interval applied
SHOT POINT
ZONE OF SUBSIDENCE
SOUTHERN LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
240 m
135 m
-0.71 m
SUBSIDENCE (m)
LINE 15 SUBSIDENCE PROFILE
1988N - 1989N (Averaging Interval 20m)
STANDARD DEVIATION 0.105 m
Longwall 1E
mN OF LONGWALL AXIS

FIGURE 30

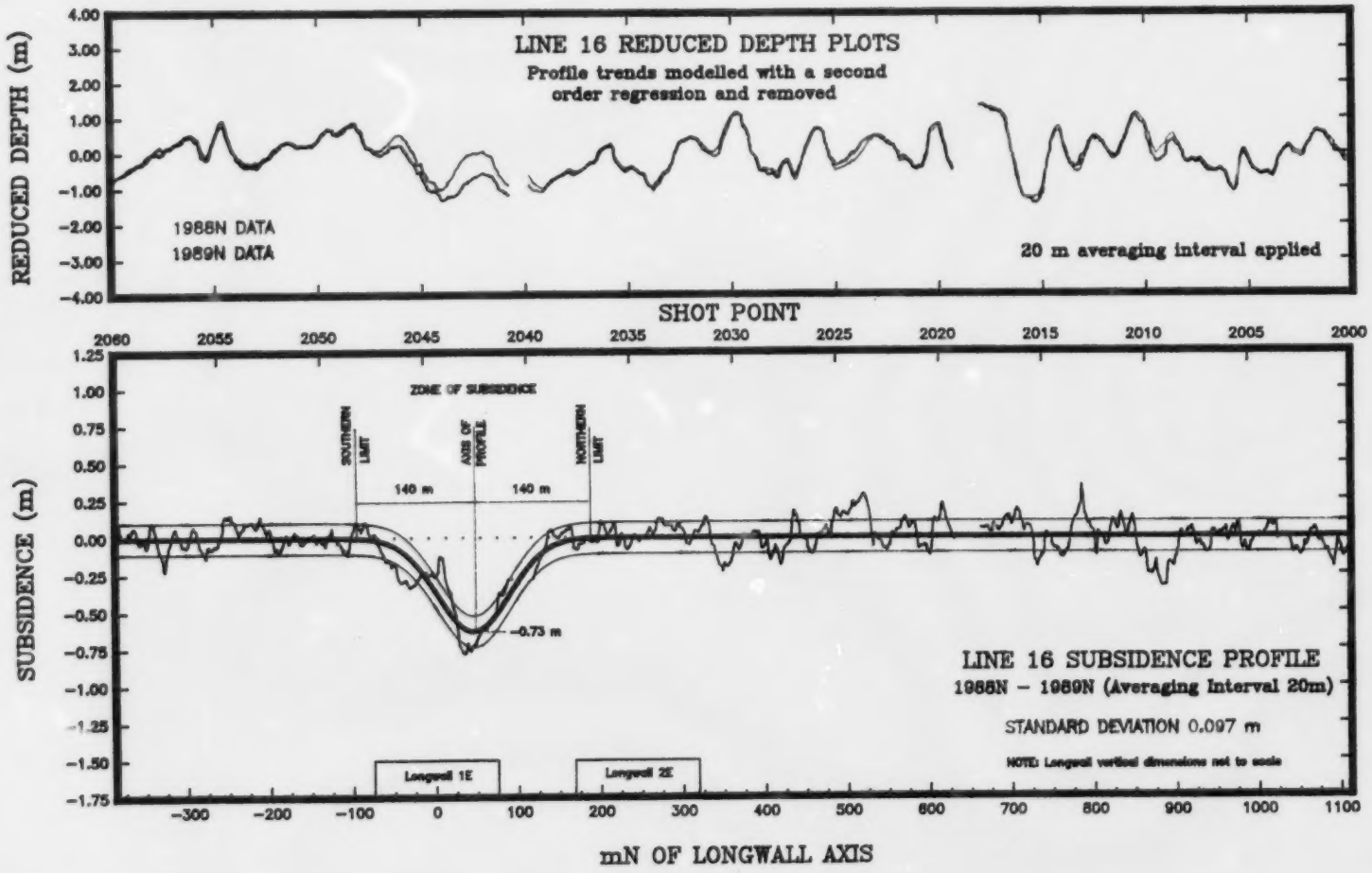
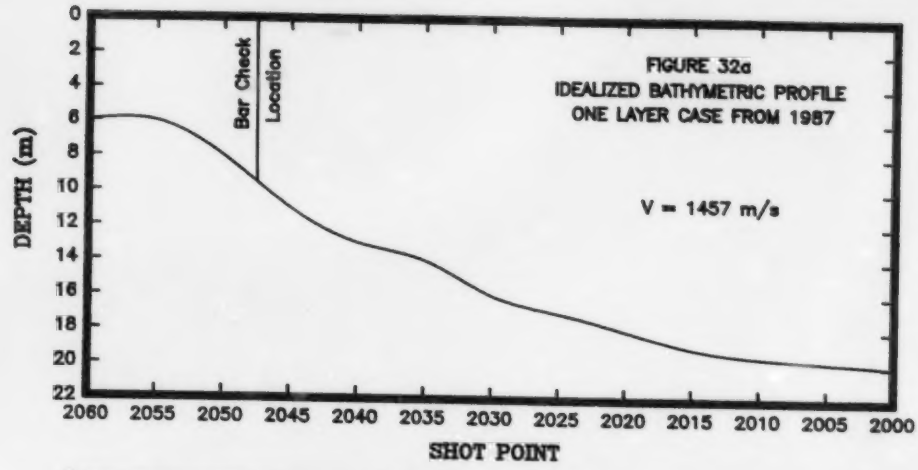
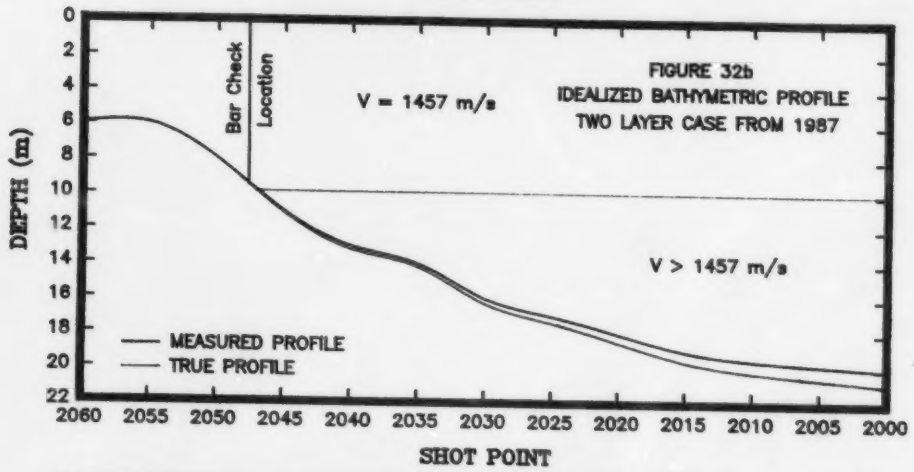
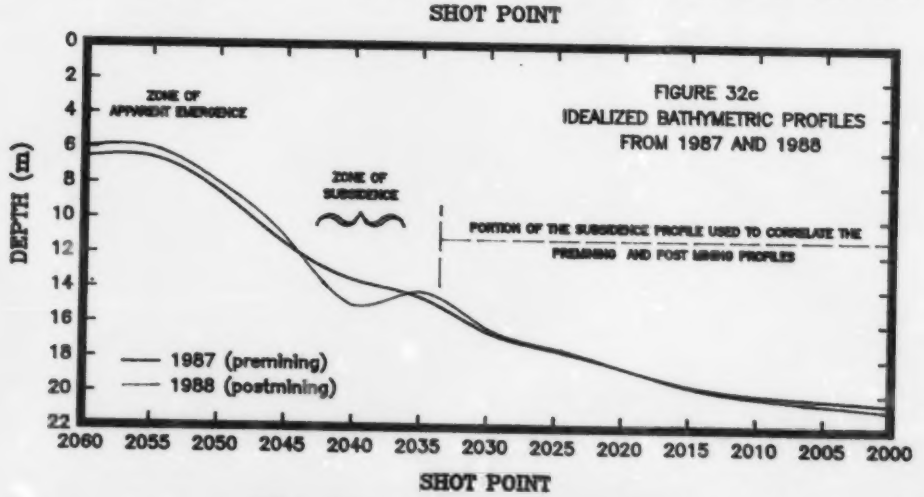

LINE 16 REDUCED DEPTH PLOTS
Profile trends modelled with a second order regression and removed
REDUCED DEPTH (m)
1988N DATA
1989N DATA
20 m averaging interval applied
SHOT POINT
SUBSIDENCE (m)
ZONE OF SUBSIDENCE
SOUTHERN LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
140 m
140 m
-0.73 m
LINE 16 SUBSIDENCE PROFILE
1988N – 1989N (Averaging Interval 20m)
STANDARD DEVIATION 0.097 m
NOTE: Longwall vertical dimensions not to scale
Longwall 1E
Longwall 2E
mN OF LONGWALL AXIS

FIGURE 31






DEPTH (m)
ZONE OF APPARENT EMERGENCE
ZONE OF SUBSIDENCE
FIGURE 32c
IDEALIZED BATHYMETRIC PROFILES
FROM 1987 AND 1988
PORTION OF THE SUBSIDENCE PROFILE USED TO CORRELATE THE PREMINING AND POST MINING PROFILES
1987 (premining)
1988 (postmining)
2060 2055 2050 2045 2040 2035 2030 2025 2020 2015 2010 2005 2000
SHOT POINT

IDEALIZED BATHYMETRIC PROFILES SHOWING THE CAUSE OF APPARENT EMERGENCE

FIGURE 32

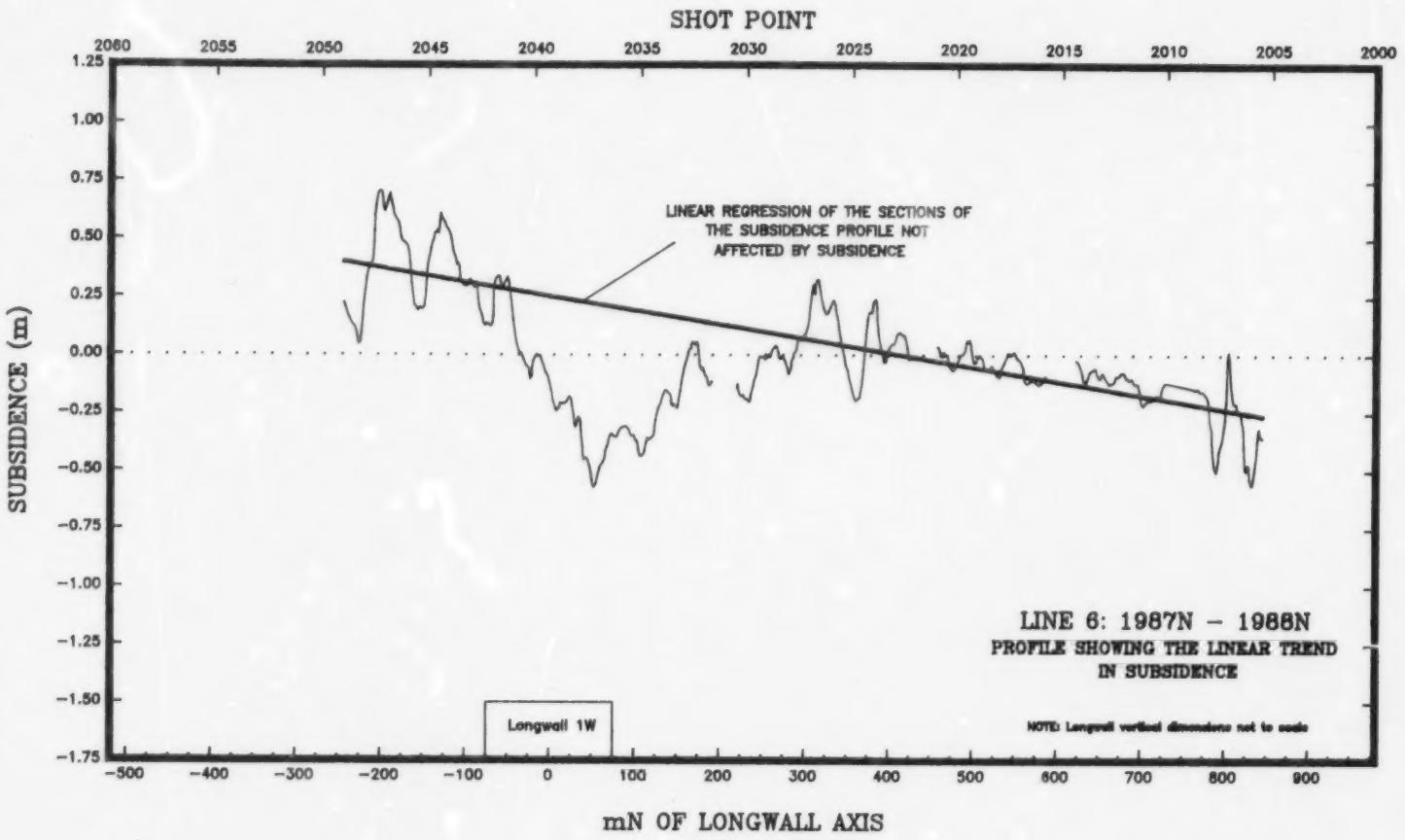

SHOT POINT
2060
2055
2050
2045
2040
2035
2030
2025
2020
2015
2010
2005
2000
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
SUBSIDENCE (m)
LINEAR REGRESSION OF THE SECTIONS OF THE SUBSIDENCE PROFILE NOT AFFECTED BY SUBSIDENCE
LINE 6: 1987N - 1986N
PROFILE SHOWING THE LINEAR TREND IN SUBSIDENCE
Longwall 1W
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
900
mN OF LONGWALL AXIS

FIGURE 33

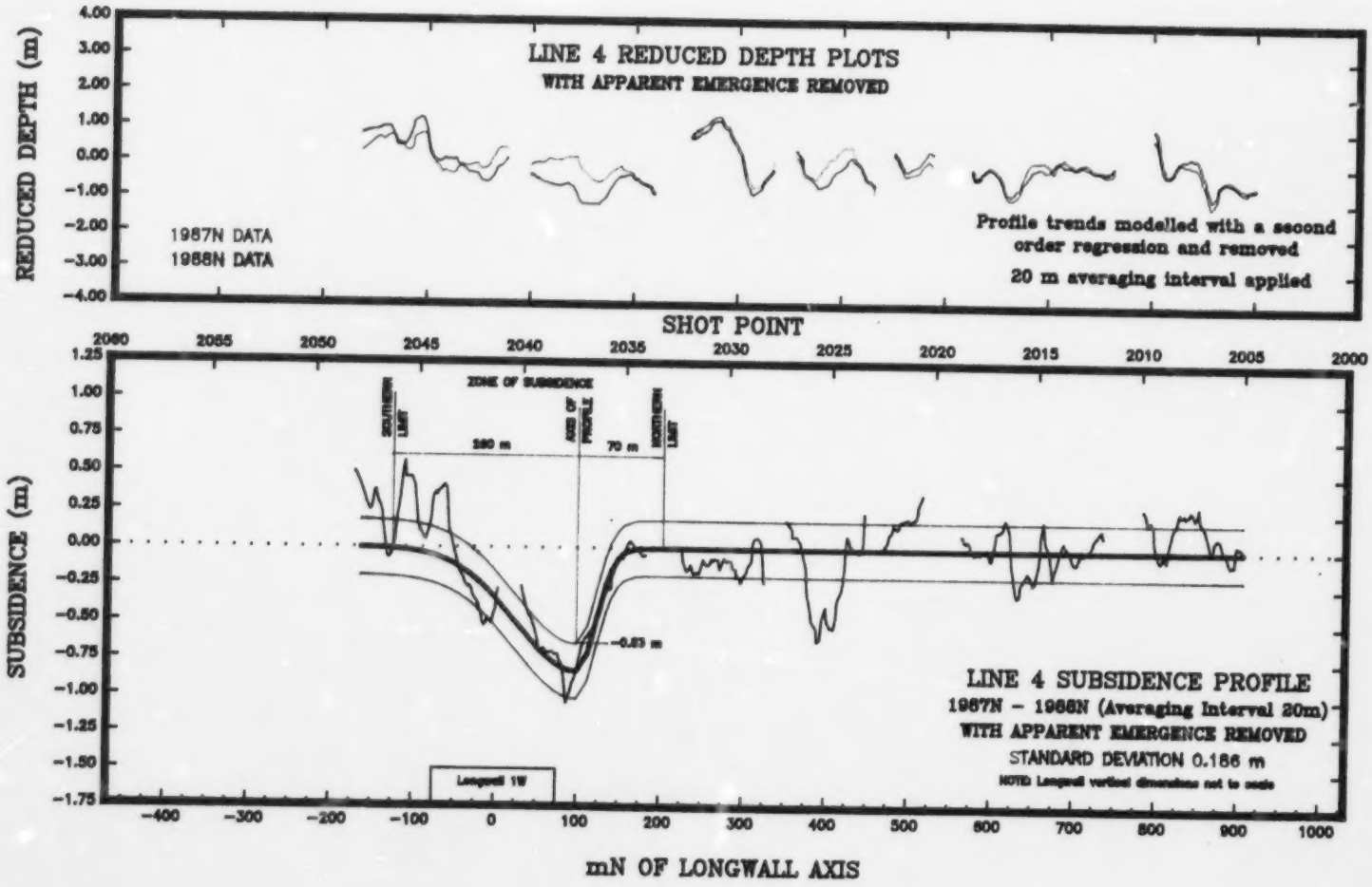

LINE 4 REDUCED DEPTH PLOTS
WITH APPARENT EMERGENCE REMOVED
REDUCED DEPTH (m)
1987N DATA
1988N DATA
Profile trends modelled with a second order regression and removed
20 m averaging interval applied
SHOT POINT
SUBSIDENCE (m)
ZONE OF SUBSIDENCE
SOUTHERN LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
280 m
70 m
-0.83 m
LINE 4 SUBSIDENCE PROFILE
1987N - 1988N (Averaging Interval 20m)
WITH APPARENT EMERGENCE REMOVED
STANDARD DEVIATION 0.166 m
Longwall 1W
mN OF LONGWALL AXIS

FIGURE 34

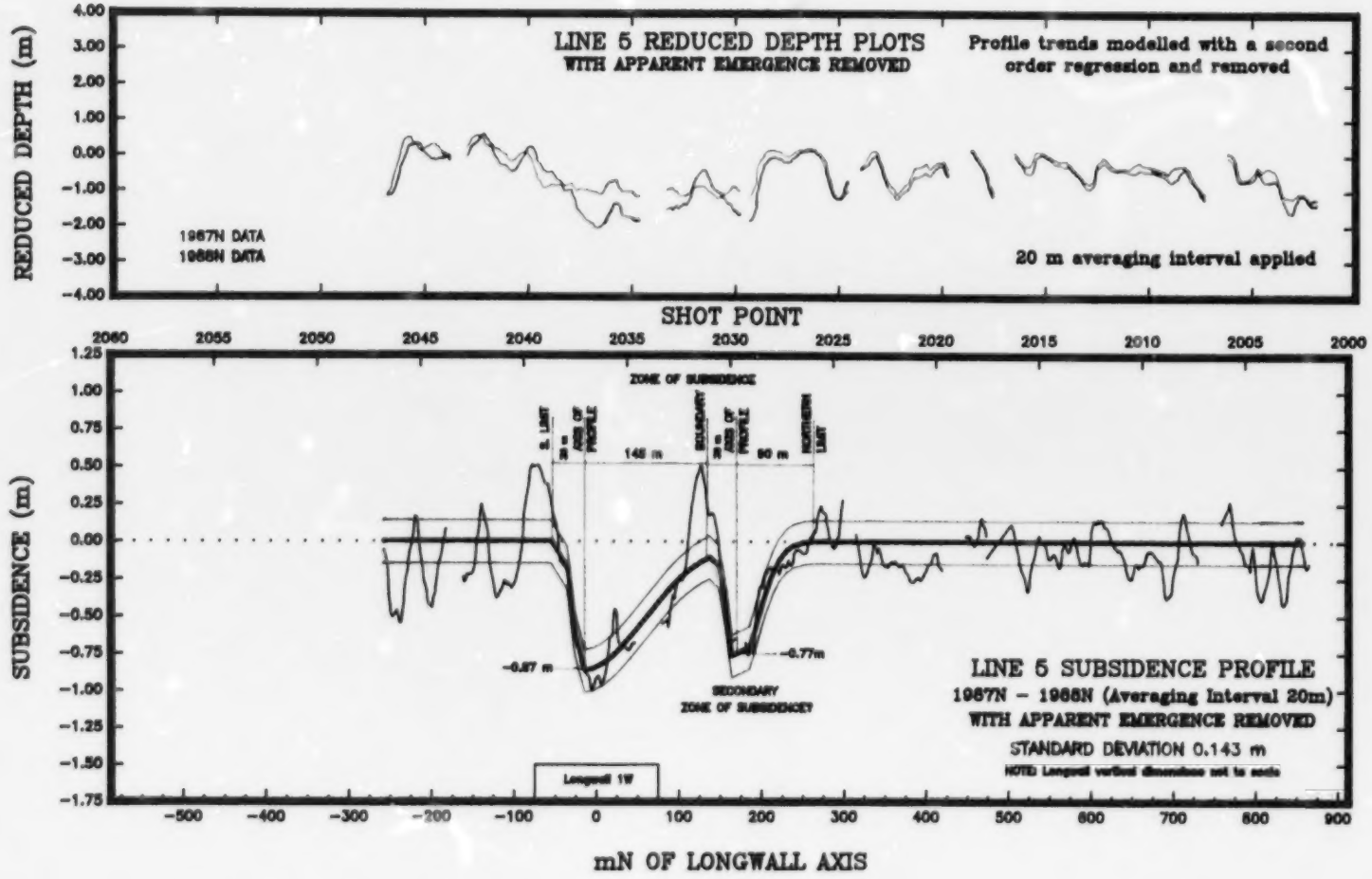

LINE 5 REDUCED DEPTH PLOTS
WITH APPARENT EMERGENCE REMOVED
Profile trends modelled with a second order regression and removed
1987N DATA
1988N DATA
20 m averaging interval applied
REDUCED DEPTH (m)
SHOT POINT
SUBSIDENCE (m)
ZONE OF SUBSIDENCE
S. LIMIT
AXIS OF PROFILE
145 m
BOUNDARY
AXIS OF PROFILE
80 m
NORTHERN LIMIT
-0.87 m
-0.77m
SECONDARY ZONE OF SUBSIDENCE
LINE 5 SUBSIDENCE PROFILE
1987N - 1988N (Averaging Interval 20m)
WITH APPARENT EMERGENCE REMOVED
STANDARD DEVIATION 0.143 m
Longwall 1W
mN OF LONGWALL AXIS

FIGURE 35

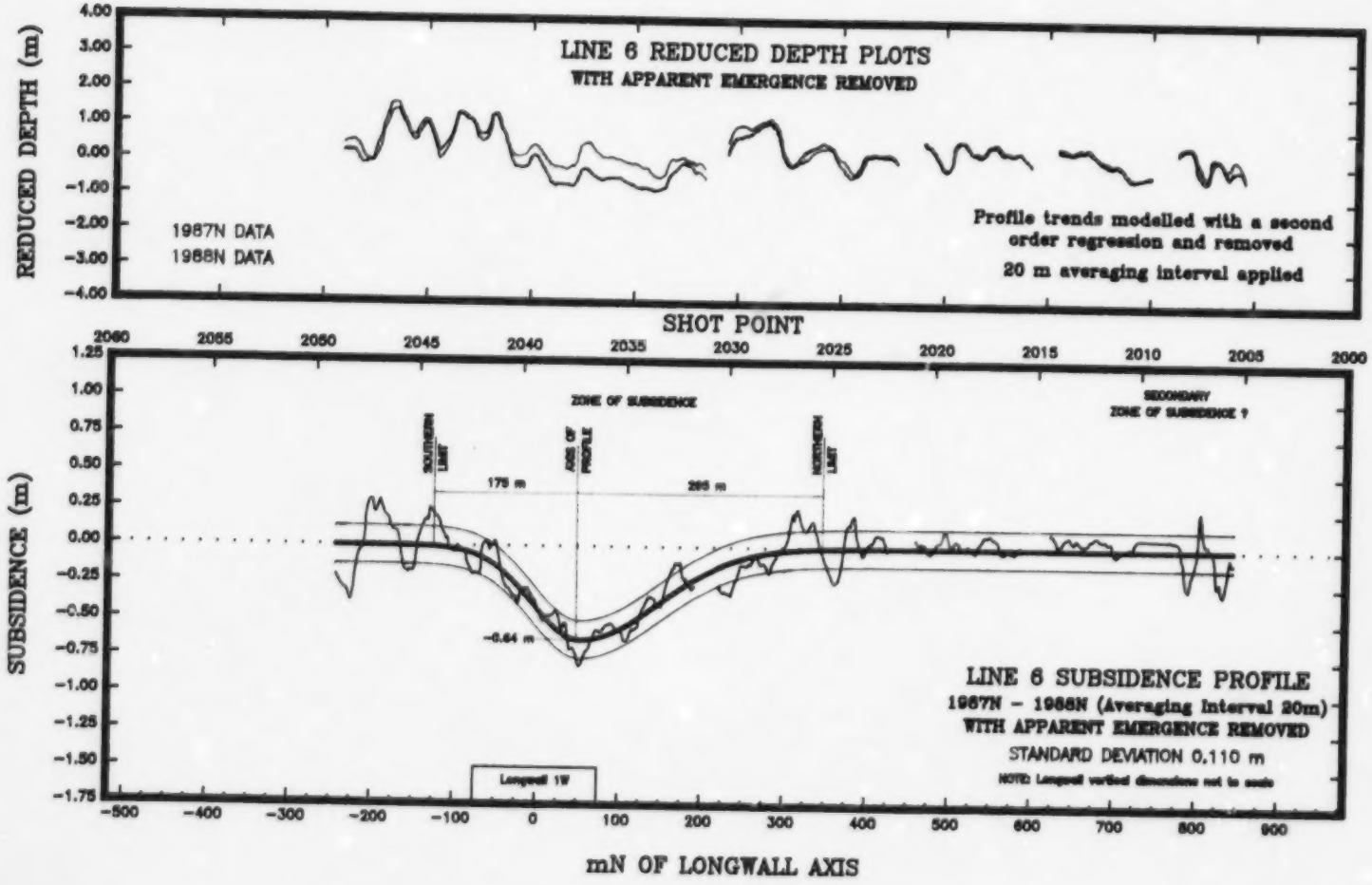

LINE 6 REDUCED DEPTH PLOTS
WITH APPARENT EMERGENCE REMOVED
REDUCED DEPTH (m)
1967N DATA
1968N DATA
Profile trends modelled with a second order regression and removed
20 m averaging interval applied
SHOT POINT
SUBSIDENCE (m)
ZONE OF SUBSIDENCE
SECONDARY ZONE OF SUBSIDENCE ?
SOUTHERN LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
175 m
295 m
-0.64 m
Longwall 1W
LINE 6 SUBSIDENCE PROFILE
1967N - 1968N (Averaging Interval 20m)
WITH APPARENT EMERGENCE REMOVED
STANDARD DEVIATION 0.110 m
mN OF LONGWALL AXIS

FIGURE 36

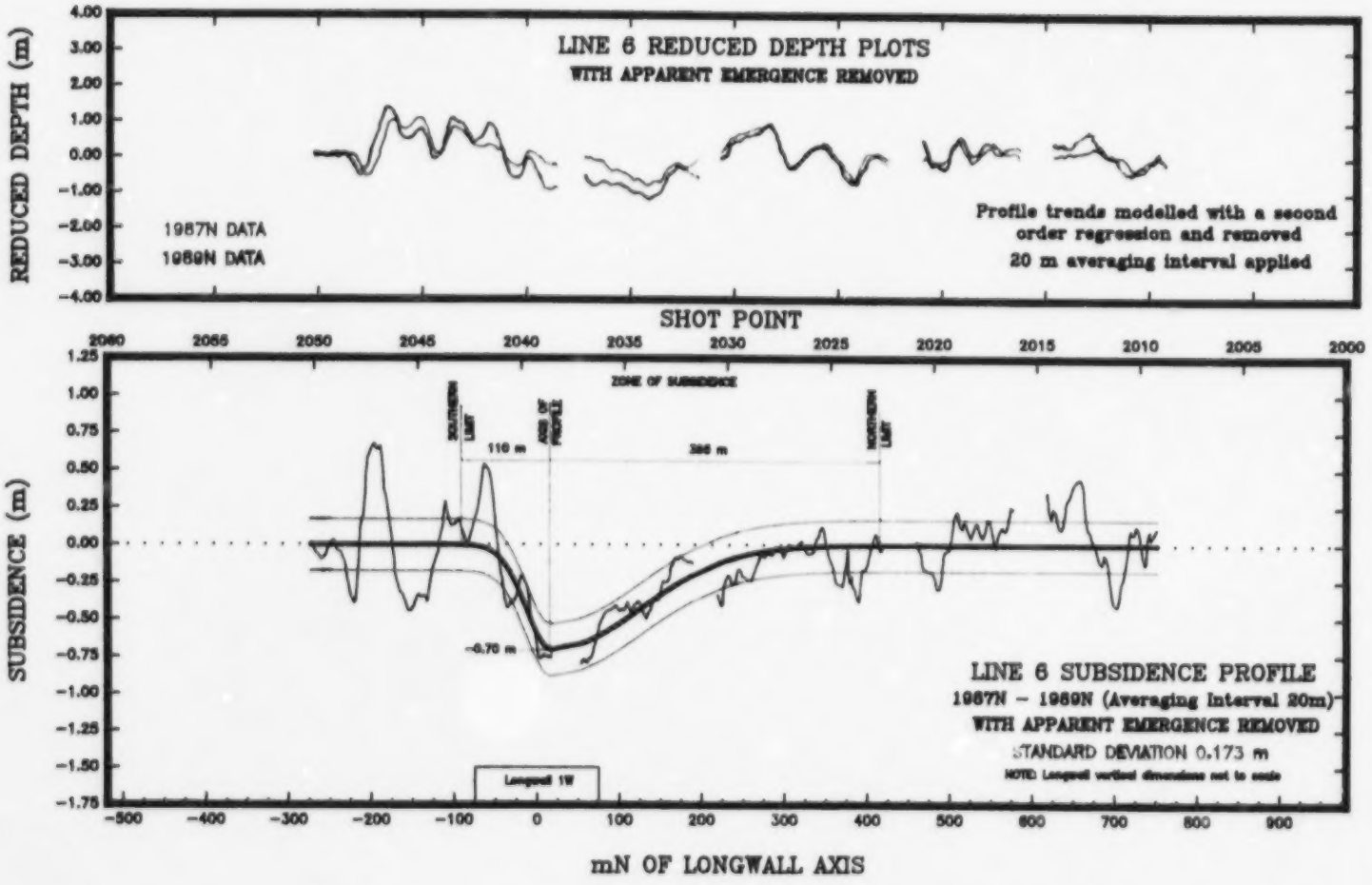

LINE 6 REDUCED DEPTH PLOTS
WITH APPARENT EMERGENCE REMOVED
REDUCED DEPTH (m)
1987N DATA
1989N DATA
Profile trends modelled with a second order regression and removed
20 m averaging interval applied
SHOT POINT
SUBSIDENCE (m)
ZONE OF SUBSIDENCE
SOUTHERN LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
110 m
386 m
-0.70 m
Longwall 1W
LINE 6 SUBSIDENCE PROFILE
1987N - 1989N (Averaging Interval 20m)
WITH APPARENT EMERGENCE REMOVED
STANDARD DEVIATION 0.173 m
mN OF LONGWALL AXIS

FIGURE 37

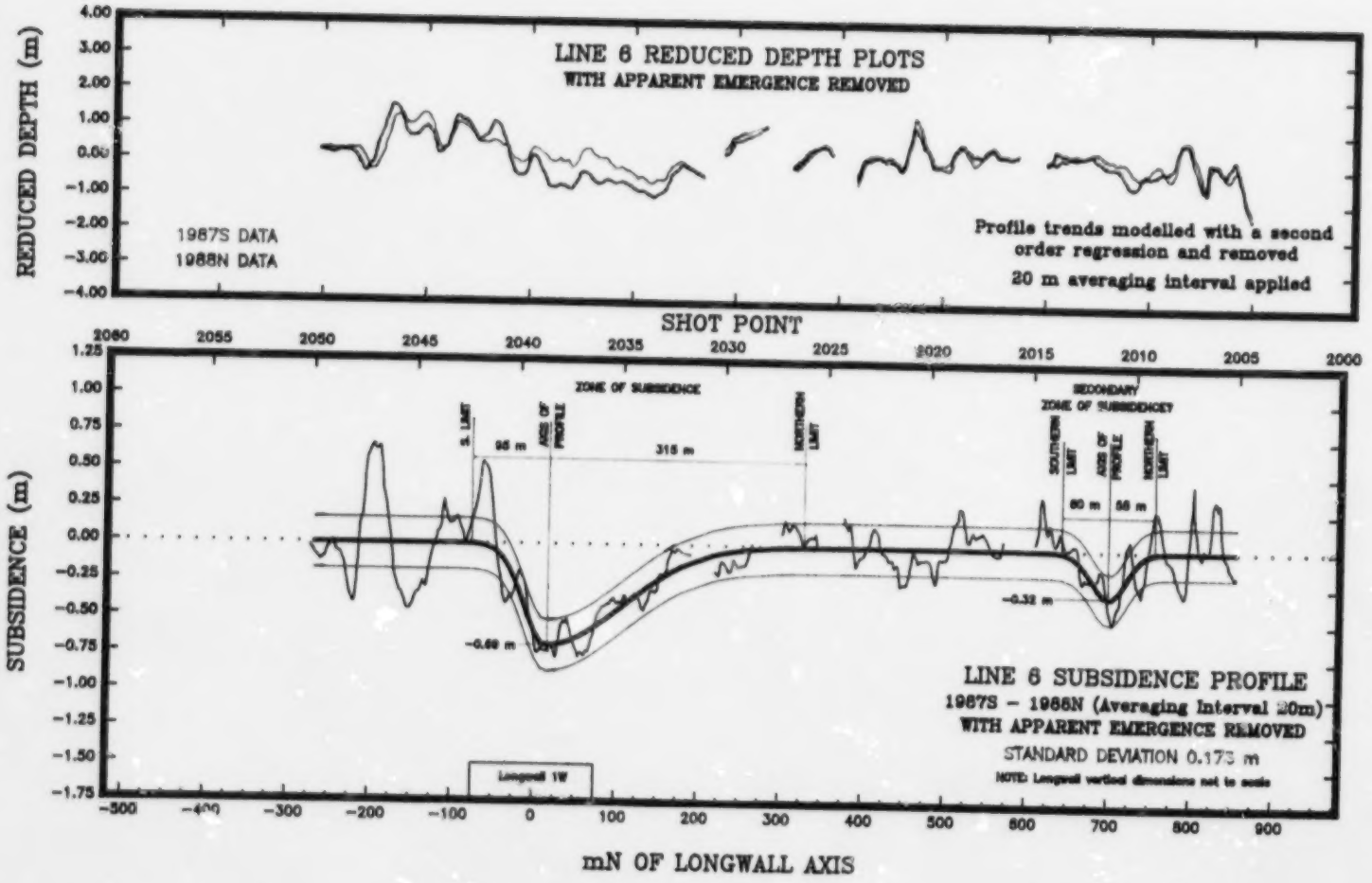

LINE 6 REDUCED DEPTH PLOTS
WITH APPARENT EMERGENCE REMOVED
REDUCED DEPTH (m)
1987S DATA
1988N DATA
Profile trends modelled with a second order regression and removed
20 m averaging interval applied
SHOT POINT
SUBSIDENCE (m)
ZONE OF SUBSIDENCE
S. LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
SECONDARY ZONE OF SUBSIDENCE
SOUTHERN LIMIT
95 m
315 m
60 m
55 m
-0.69 m
-0.32 m
LINE 6 SUBSIDENCE PROFILE
1987S - 1988N (Averaging Interval 20m)
WITH APPARENT EMERGENCE REMOVED
STANDARD DEVIATION 0.173 m
Longwall 1W
mN OF LONGWALL AXIS

FIGURE 38

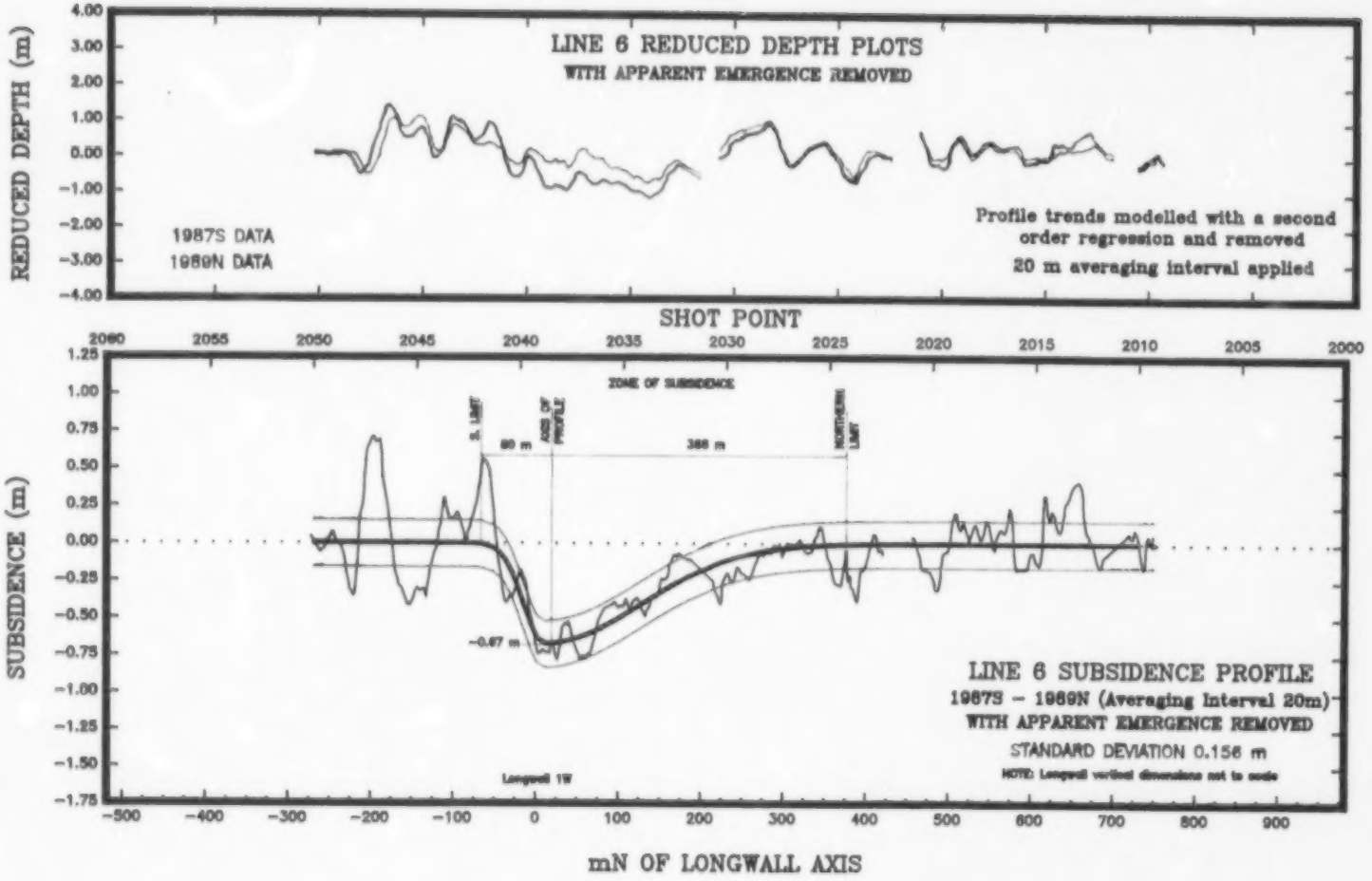

LINE 6 REDUCED DEPTH PLOTS
WITH APPARENT EMERGENCE REMOVED
REDUCED DEPTH (m)
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
1987S DATA
1989N DATA
Profile trends modelled with a second order regression and removed
20 m averaging interval applied
SHOT POINT
2060
2055
2050
2045
2040
2035
2030
2025
2020
2015
2010
2005
2000
SUBSIDENCE (m)
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
ZONE OF SUBSIDENCE
S. LIMIT
AXIS OF PROFILE
NORTHERN LIMIT
80 m
388 m
-0.67 m
LINE 6 SUBSIDENCE PROFILE
1987S - 1989N (Averaging Interval 20m)
WITH APPARENT EMERGENCE REMOVED
STANDARD DEVIATION 0.156 m
Longwall 1W
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
900
mN OF LONGWALL AXIS

FIGURE 39

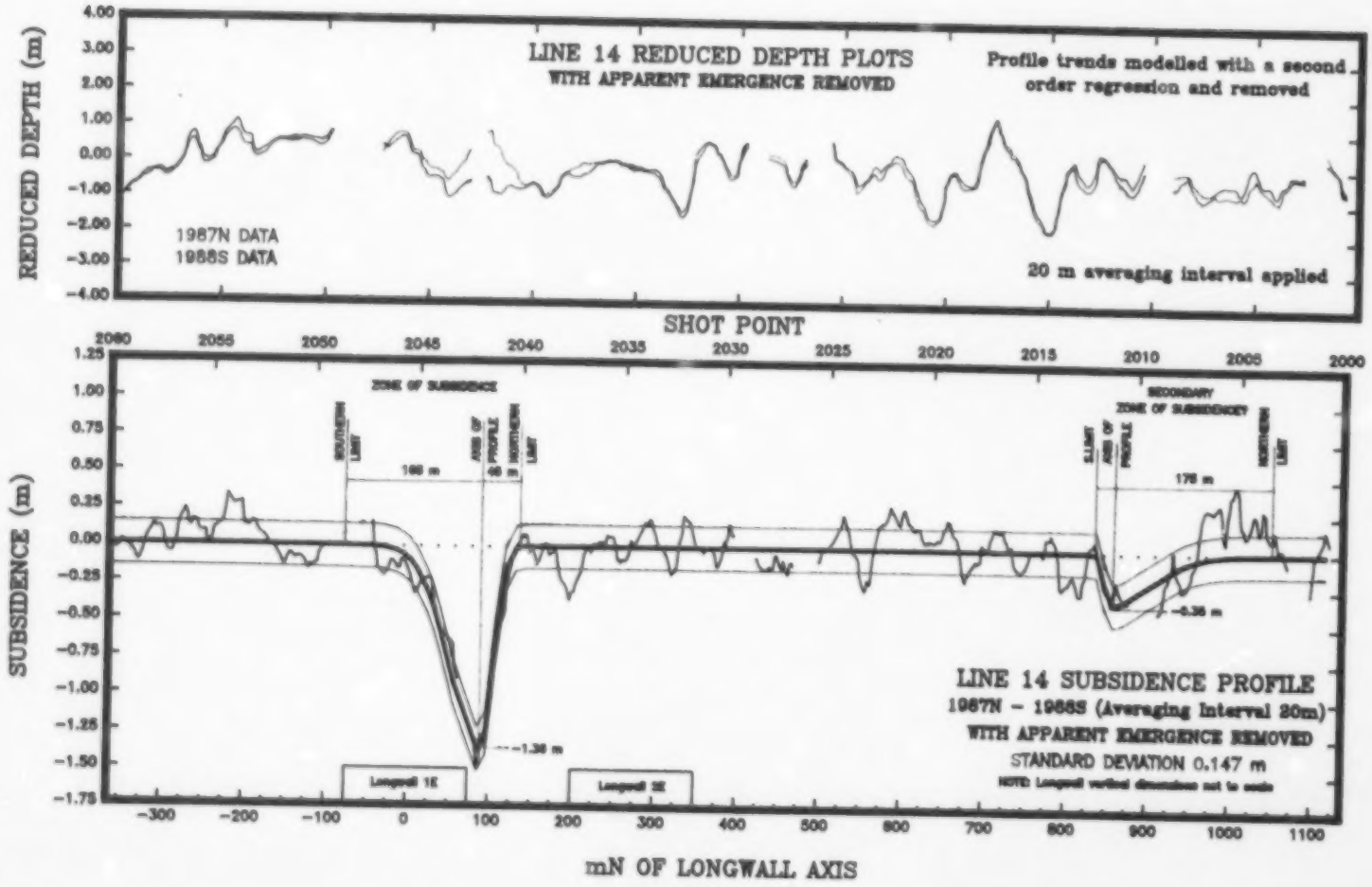

LINE 14 REDUCED DEPTH PLOTS
WITH APPARENT EMERGENCE REMOVED
Profile trends modelled with a second order regression and removed
1987N DATA
1988S DATA
20 m averaging interval applied
REDUCED DEPTH (m)
SHOT POINT
SUBSIDENCE (m)
ZONE OF SUBSIDENCE
SECONDARY ZONE OF SUBSIDENCE
LINE 14 SUBSIDENCE PROFILE
1987N - 1988S (Averaging Interval 20m)
WITH APPARENT EMERGENCE REMOVED
STANDARD DEVIATION 0.147 m
mN OF LONGWALL AXIS

FIGURE 40

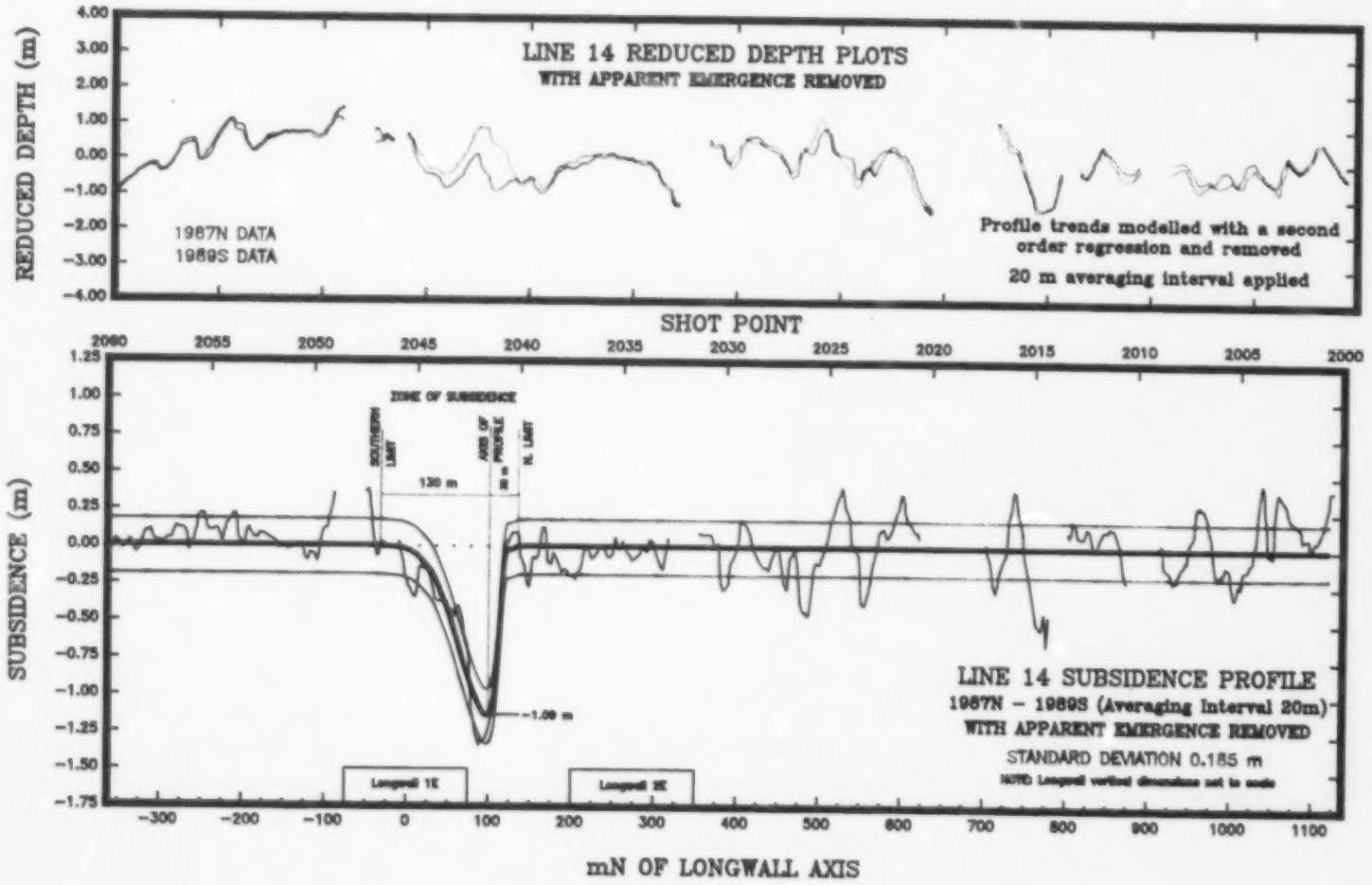

LINE 14 REDUCED DEPTH PLOTS
WITH APPARENT EMERGENCE REMOVED
REDUCED DEPTH (m)
1987N DATA
1989S DATA
Profile trends modelled with a second order regression and removed
20 m averaging interval applied
SHOT POINT
SUBSIDENCE (m)
ZONE OF SUBSIDENCE
130 m
-1.09 m
LINE 14 SUBSIDENCE PROFILE
1987N – 1989S (Averaging Interval 20m)
WITH APPARENT EMERGENCE REMOVED
STANDARD DEVIATION 0.185 m
mN OF LONGWALL AXIS

FIGURE 41

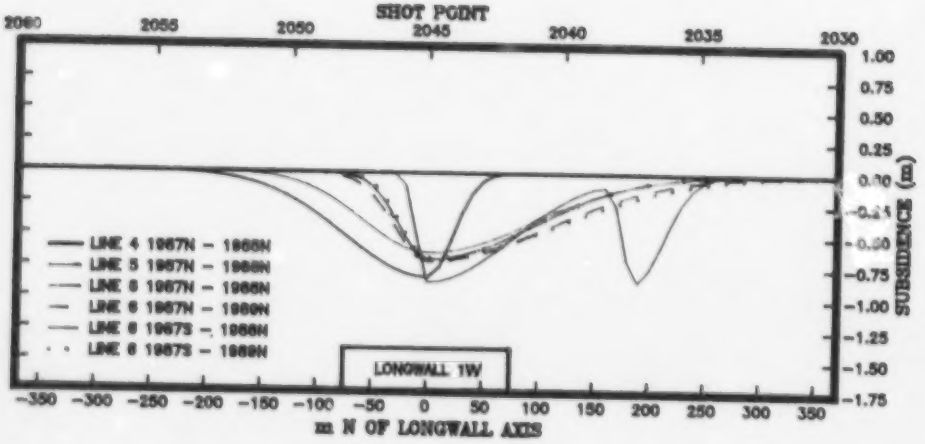


FIGURE 42

SUBSIDENCE CURVES
DERIVED FROM LINES 4, 5, AND 6

NOTES: 1) Longwall vertical dimensions not to scale
2) Curves shifted horizontally such that profile axes are aligned with longwall axis

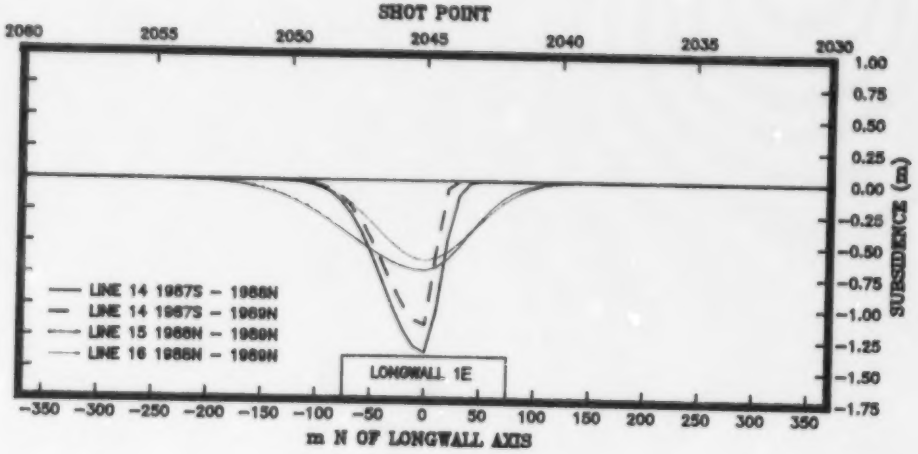


FIGURE 43

SUBSIDENCE CURVES
DERIVED FROM LINES 14, 15, AND 16

NOTES: 1) Longwall vertical dimensions not to scale
2) Curves shifted horizontally such that profile axes are aligned with longwall axis

APPENDIX 2

TABLES

TABLE 1

DEPTH OFFSET VS TRACK OFFSET LINE PAIR COMBINATIONS FOR BATHYMETRIC LINES FROM 1987, 1988 AND 1989

LINE NUMBER	LINE NUMBER
1987N	1987S
1987N	1988N
1987N	1988S
1987N	1989N
1987N	1989S
1987S	1988N
1987S	1988S
1987S	1989N
1987S	1989S
1988N	1988S
1988N	1989N
1988N	1989S
1989S	1989N
1989S	1989S
1989N	1989S

NOTE: No 1987 data was collected on Line 15 and 16 in the 1987 survey. Therefore only the last six combinations were examined in the analysis of track offset vs depth offset done on the data from Line 15.

TABLE 2

LINE PAIRS USED TO GENERATE SUBSIDENCE PROFILES

LINE NUMBER	LINE PAIR
4	1987N - 1988N
5	1987N - 1988N
6	1987N - 1988N 1987N - 1989N 1987S - 1988N 1987S - 1989N
14	1987S - 1988N 1987S - 1989N
15	1988N - 1989N
16	1988N - 1989N

TABLE 3

COEFFICIENTS FROM CURVES FIT TO SUBSIDENCE PROFILES
(primary zones of subsidence only)

3a
Prior to Removal of Apparent Emergence

LINE NO.	FIGURE NO.	m (m)	s (m)	t (m)	b (m)	d (m)	c (m)
4 (1987N-1988N)	22	91.40	20.35	94.94	1.49	3.33	0.74
5 (1987N-1988N)	23	-16.43	10.00	43.95	1.37	2.23	0.34
6 (1987N-1988N)	24	53.38	62.67	77.67	1.02	2.00	0.39
6 (1987N-1989N)	25	16.58	31.71	80.23	1.33	2.08	0.30
6 (1987S-1988N)	26	20.04	32.15	81.99	1.63	2.14	0.20
6 (1987S-1989N)	27	13.77	28.89	100.00	1.56	2.04	1.19
14 (1987S-1988N)	28	106.76	54.00	5.00	2.75	3.43	0.27
14 (1987S-1989N)	29	90.84	44.413	12.85	3.47	4.06	0.24
15 (1988N-1989N)	30	48.71	69.52	39.26	1.79	---	---
16 (1988N-1989N)	31	47.06	43.77	43.77	1.57	---	---

3b
After Removal of Apparent Emergence

LINE NO.	FIGURE NO.	m (m)	s (m)	t (m)	b (m)
4 (1987N-1988N)	34	99.73	74.71	22.21	2.09
5 (1987N-1988N)	35	-17.75	9.51	75.00	2.18
6 (1987N-1988N)	36	52.47	58.02	94.76	1.59
6 (1987N-1989N)	37	17.39	30.51	109.19	1.76
6 (1987S-1988N)	38	13.62	26.41	94.19	1.73
6 (1987S-1989N)	39	10.22	24.68	117.83	1.69
14 (1987S-1988N)	40	91.42	38.20	13.55	3.43
14 (1987S-1989N)	41	102.31	37.306	8.31	2.88
15 (1988N-1989N)	30	48.71	69.52	39.26	1.79
16 (1988N-1989N)	31	47.06	43.77	43.77	1.57

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TABLE 4

SUMMARY OF INITIAL SUBSIDENCE PROFILE CHARACTERISTICS
(Prior to the Removal of Apparent Emergence)

LINE NO.	LINE PAIR	MAX SUBS (m)	AXIS POSITION (mN of longwall axis)	TOTAL LENGTH SUBS (m)	LENGTH SUBS AREA S OF LONGWALL AXIS (m)	LENGTH SUBS AREA N OF LONGWALL AXIS (m)	STANDARD DEVIATION (m)	APPARENT EMERGENCE (m)
4	1987N-1988N	0.80	91	170	105	65	0.17	0.74
5	1987N-1988N	0.55	-16	145	15	130	0.19	0.34
	1987N-1988N(a)	0.59	175	85	35	50	0.19	---
6	1987N-1988N	0.40	53	325	75	250	0.13	0.39
	1987N-1989N	0.85	20	335	55	280	0.17	0.20
	1987S-1988N	0.53	17	315	45	270	0.14	0.30
	1987S-1988N(a)	0.28	695	335	85	250	0.14	---
	1987S-1989N	0.61	14	350	50	300	0.15	---
14	1987S-1988N	1.38	91	135	90	45	0.13	0.24
	1987S-1988N(a)	0.40	900	305	210	95	0.13	---
	1987S-1989N	1.10	107	115	95	20	0.17	0.27
15	1988N-1989N	0.71	49	375	240	135	0.11	---
16	1988N-1989N	0.75	47	280	140	140	0.10	---
Averages of Primary Zones of Subsidence		0.77	47	255	91	164	0.15	0.31

a) Secondary zone of subsidence

TABLE 5

SUMMARY OF SUBSIDENCE PROFILE CHARACTERISTICS
(After Removal of Apparent Emergence)

LINE NO.	LINE PAIR	MAX SUBS (m)	AXIS POSITION (mN of longwall axis)	TOTAL LENGTH SUBS (m)	LENGTH SUBS AREA S OF LONGWALL AXIS (m)	LENGTH SUBS AREA N OF LONGWALL AXIS (m)	STANDARD DEVIATION (m)
4	1987N-1988N	0.83	100	330	260	70	0.19
5	1987N-1988N	0.87	-18	180	35	145	0.14
	1987N-1988N(a)	0.77	169	125	35	90	0.14
6	1987N-1988N	0.64	52	470	175	295	0.11
	1987N-1989N	0.70	17	505	110	395	0.17
	1987S-1988N	0.69	13	410	95	315	0.17
	1987S-1988N(a)	0.32	700	115	60	55	0.17
	1987S-1989N	0.67	10	440	80	360	0.16
14	1987S-1988N	1.36	91	210	165	45	0.15
	1987S-1988N(a)	0.35	850	190	15	175	0.15
	1987S-1989N	1.09	102	145	130	35	0.19
15	1988N-1989N	0.71	49	375	240	135	0.11
16	1988N-1989N	0.75	47	280	140	140	0.10
Averages of primary zones of subsidence		0.83	46	335	143	193	0.15

a) Secondary zone of subsidence